Climate friendly agriculture

Evaluations and improvements for energy and greenhouse gas emissions at the farm level in the European Union

With the contribution of the LIFE+ financial instrument of the European Community

Foreword

“Making European agriculture more climate friendly and climate resilient is not a choice, but a serious need and obligation. The proposal for the new CAP will help farmers to better deal with climate change challenges”

Jerzy Plewa, Director General for Agriculture of the European Commission, April 2013.

Better farming for better climate: a European perspective

In a few decades, the horizon has changed. Whereas twenty years ago, climate change was a subject of scientist study, it now counts as one of the major issues of public policy. In agriculture, as in other sectors, climate change represents a double challenge: reducing its GHG emissions (mitigation) while adapting to the expected consequences of global warming which will be more and more confronted (adaptation).

To meet this dual challenge requires to rethink some production methods, yet widely proven, but that lead to fragile systems or strong climatic and environmental consequences. This effort to support change also opens up a wide range of new opportunities, such as developing more low inputs systems and renewables energies.

Agricultural GHG emissions from the EU have decreased by over 20% since 1990, due to the significant reduction of livestock and more effective application of mineral nitrogen fertilizers. Despite these significant efforts and face to the scale of the problem, farming must continue to contribute to GHG mitigation and to reduce fossil energies consumption.

The European Commission has started to work on preparing a new climate and energy package in 2030. Some targeted mitigation objectives more ambitious and broader than the existing ones will be proposed. The identification of public policy instruments to further reduce emissions from activities and agricultural soils is a major task for the coming years. Some sufficient incentives are also needed to support farmers in their efforts to adapt agricultural structures and production methods. 2014-2020 CAP reform focuses on the objectives of natural resources conservation and climate protection, which will condition a part of the direct payments and finance in the context of the rural development.

Given the technical complexity of the actions to be implemented, information procedure, training and support will be necessary for EU farmers to engage in GHG reduction. Projects like *AgriClimateChange* contribute in an effective way to a greater awareness of the issues and possible solution, as well as sharing experiences in different contexts and farming systems. This manual proves that actions are possible and viable, shows some levers to mobilize and put forward successful initiatives. It contributes to the dissemination of information and climate friendly farming practices in order to support sustainable growth.

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Photo : Jordi Domingo-FGN

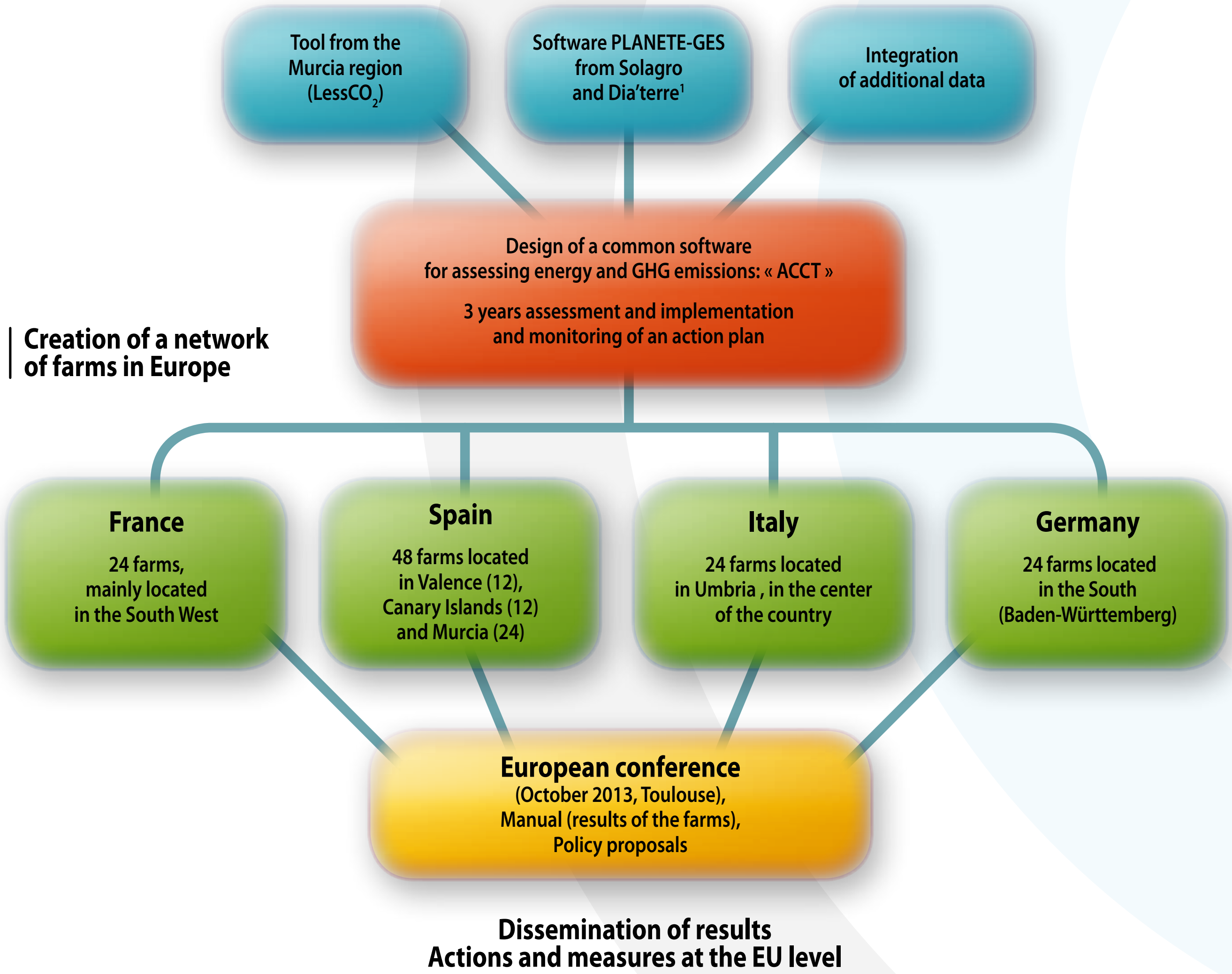
The *AgriClimateChange* project has been developed simultaneously in four European countries (France, Germany, Italy and Spain) between September 2010 and December 2013: its objective is to determine and support farming practices that best contribute to combating climate change.

Curbing greenhouse gas (GHG) emissions on farms and adapting to climate change are major challenges facing European agriculture over the coming years. Promoting farming systems that combat climate change is a powerful tool to improve climate conditions, preserve nature and increase the viability of the agricultural sector.

The project is funded by the EU's LIFE+ Programme and is coordinated by Fundación Global Nature, a Spanish foundation that has been working for 20 years promoting nature conservation and sustainable farming practices. The partnership includes organizations, private or public, with extensive experience in farming and climate change. They provide different insights to the project. In France, Solagro has been a reference in sustainable farming, energy and natural resources management since its creation in 1981. The Lake Constance Foundation works towards sustainable economy in the international Lake Constance area (Germany) and beyond. Comunità Montana Associazione dei Comuni Trasimeno-Medio Tevere is a public body in charge of sustainable local development under a national and regional law and is responsible for the Lake Trasimeno Regional Park (Italy). The Consejería de Agricultura y Agua is the Department of the Regional Government of the Murcia Region (Spain) in charge of Agriculture, Fisheries, Water and Environment.

The project gave birth to a software tool, ACCT (AgriClimateChange Tool), based on the experience of project partners, especially Solagro, which has created similar assessment tools since 1999. ACCT evaluates energy consumption, greenhouse gas emissions and carbon storage at farm level. ACCT is intended to be applicable throughout the European Union and has been continuously improved throughout the project, based on implementation in the four countries.

More than **120 farms** have been assessed with ACCT over the 3 years of the project. Taking into account the assessment results, Action Plans were developed aiming at reducing energy consumption and GHG emissions of the farms by between **10 to 40%**.



Experts identified key issues, in the farm management, offering room for improvement in terms of energy consumption and GHG emissions – where possible, opportunities for associated savings were also identified, in a context of rising energy prices. These action plans also include a list of proposed measures discussed and agreed with the farmer.

These measures were implemented with the support of the project's experts, and their impacts were measured through annual assessments in 2011 and 2012 – when necessary, additional measures were proposed.

The results and lessons obtained through the project led to the drafting of Global Proposals for EU, national and regional policy measures, especially in the context of the Common Agricultural Policy (CAP). The project partners met with the European Commission and Parliament several times during the project in order to suggest policy measures in relation to climate change in agriculture.

The project also included various communication and awareness-raising activities in order to reach key stakeholders such as farmers, Farmers Unions, professional associations or consumers.

In conclusion, the objective of the *AgriClimateChange* project is to contribute to making the European farming sector an international leader in terms of climate change, considering the key role of farmers in a sector that serves different purposes, not only food production but also the protection of biodiversity, cultural heritage, landscapes…and the climate.

[1] Dia'terre is the French software tool to assess energy and GHG, developed by ADEME with the contribution of many agricultural partners, including the Ministry of agriculture and Solagro. It centralizes all the assessments realized at the national level into a common database and provides a harmonized approach between productions. http://www2.ademe.fr/servlet/KBaseShow?sort=-1&cid=96&m=3&catid=24390

A common tool for assessing farms

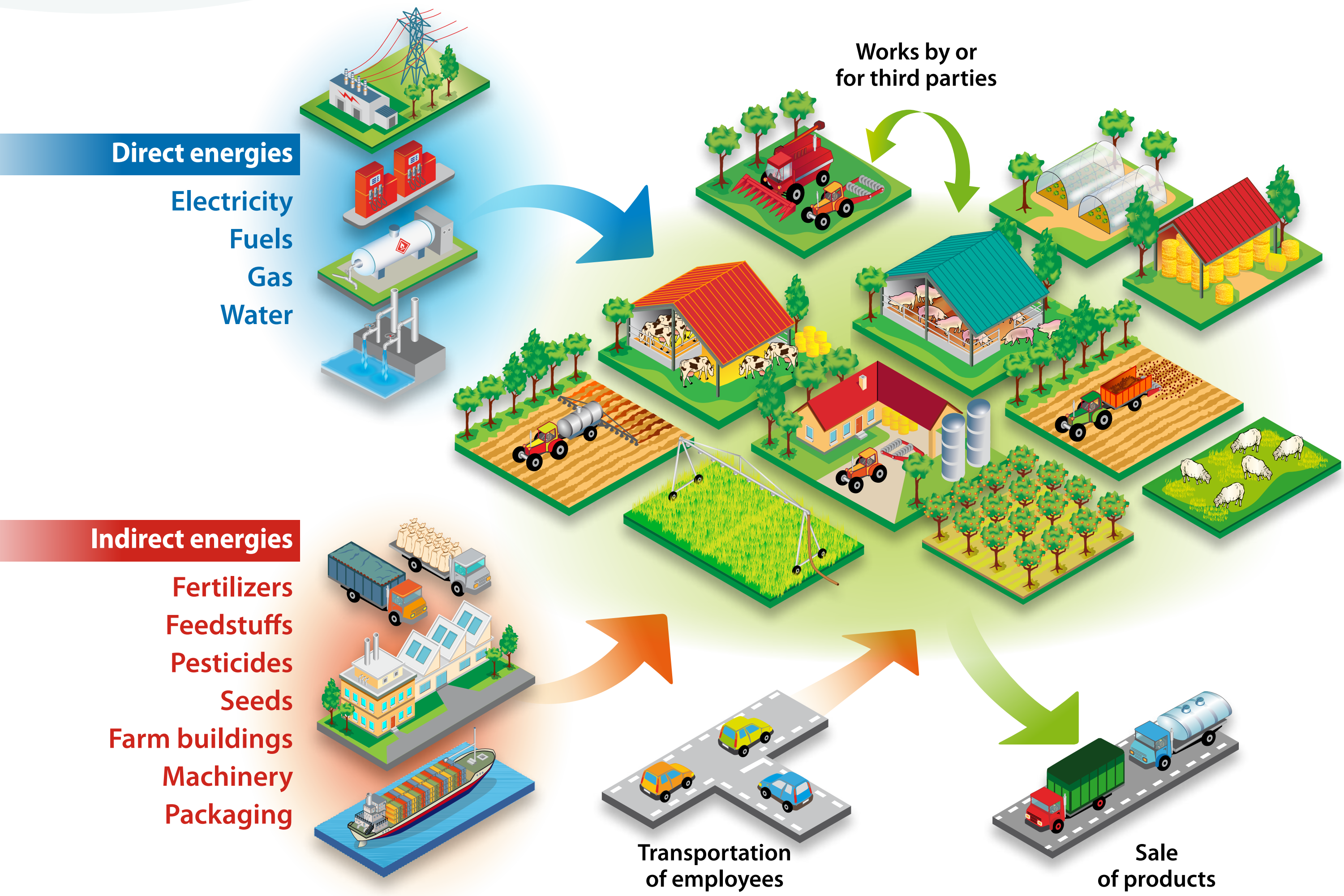
AgriClimateChange Tool (ACCT) allows evaluating over a period year non-renewable energy consumptions, GHG emissions and variations in the carbon storage at the farm level. The results from these assessments are the basis for the design of appropriate mitigation measures for the farm.

Implementation of the assessment

The first step is to interview the farmer in order to collect all the necessary data for the development of the assessment. The perimeter in ACCT is the farm level as a whole, although it is possible, as well, to perform an analysis in relation to a product (up to 5 different products can be analysed in the same farm). At this meeting with the farmer, all the registration documents ensuring traceability of the agricultural practices of the farm must be gathered: CAP statement, notebooks relating to spreading fertilizers and pesticides, the accounting of the farm, bills for fuel or electricity and for the main inputs used on the farm… The evaluation of the farm is carried out in reference to a whole year, so it is usually the latest completed cropping season. During the data collection phase, the auditor should, beyond the quantification of the annual inputs, take the time to talk with the farmer to understand the overall functioning of the farm as well as the strategies implemented. A visit to the farm is recommended to strengthen the understanding of the functioning as well as to identify useful elements not pointed out by the farmer. This phase takes about a day.

Sources of direct and indirect energies taken into account in ACCT

• Figure 1



Energy consumption

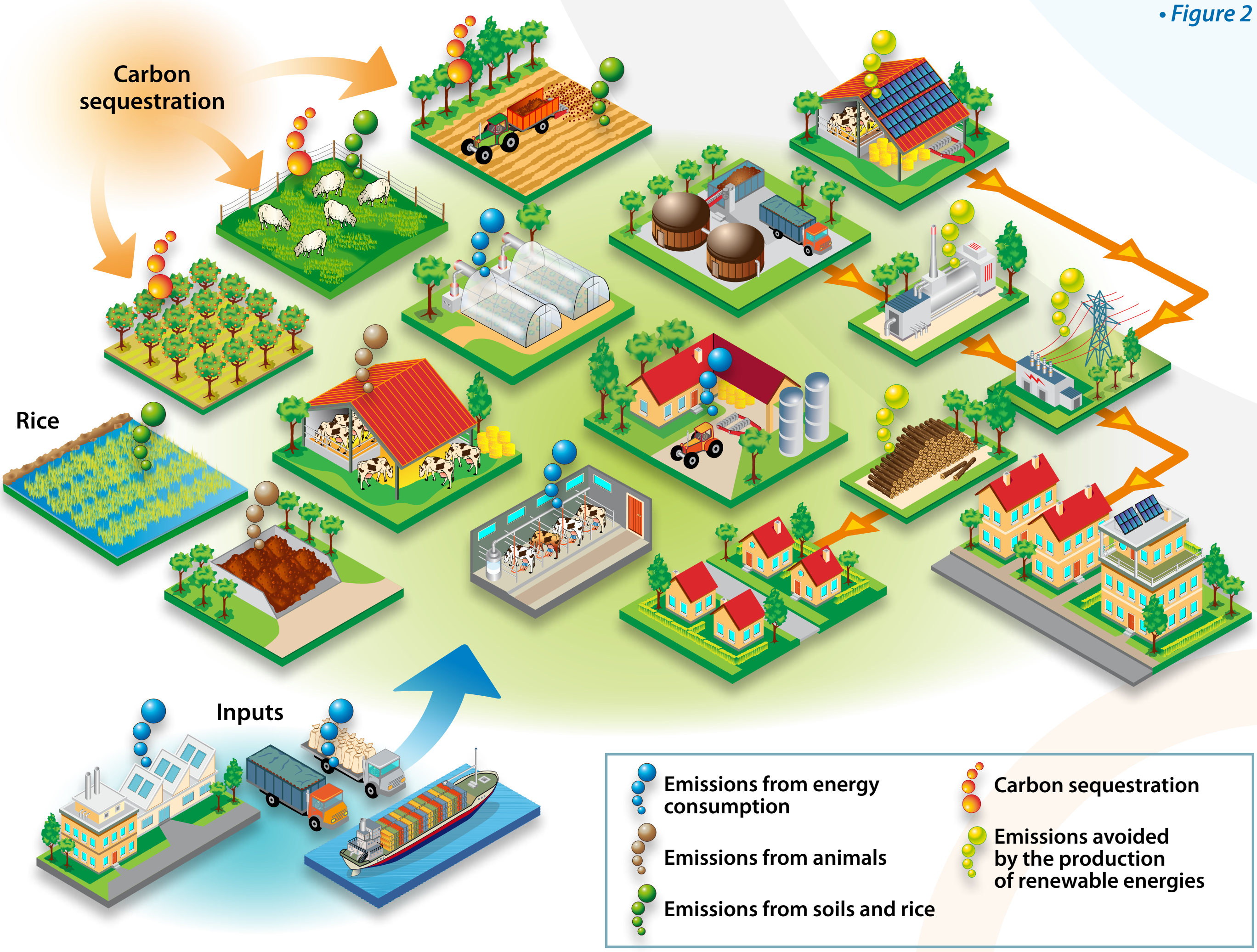
ACCT assesses both the direct non-renewable energy consumptions (fuel, electricity, gas…) and the indirect ones through all the elements included in a cropping season (mineral fertilizers, feedstuffs purchased, machinery, farm buildings…). In accordance with the principle of the LCA[1], each direct or indirect energy item is associated to an energetic coefficient. This calculation refers to a wider perimeter that can include the extraction, manufacturing and transportation activities. Thus, the upstream of the farm is systematically taken into account in the assessment. The activities of processing and transportation of agricultural products are systematically integrated into the energy analysis if they are performed by the farmer. Otherwise, the energy analysis is then stopped at the farm perimeter. The energy results are expressed in primary energy and the unit used is GJ[2]. The advantage of this system is that both direct and indirect energies can help to define the farm's energy profile.

GHG emissions and variations in the carbon storage

The assessed greenhouse gases are CO_2 (carbon dioxide), CH_4 (methane), and N_2O (nitrous oxide). These are the main GHGs under the Kyoto Protocol related to farming. GHG emissions related to the operation of chillers and air conditioning (HFCs, hydrofluorocarbons) are also taken into account, even if generally their impacts are not significant on farms. Calculations of GHG emissions and carbon sequestration are made for each specific unit of

Sources of GHG emissions, of carbon stock change and GHG emissions avoided by the production of renewable energies included in ACCT

• *Figure 2*



[1]Life cycle analysis
[2]Gigajoule

gas (weight of CO_2, CH_4 or N_2O), and converted to tonnes of CO_2 equivalent (tCO_2e) using the Global Warming Potential (GWP) of each gas (IPCC, 2007). The GWP is calculated on a fixed horizon of 100 years to take into account the duration of residence of various substances in the atmosphere. Thus, 1 tonne of CH_4 is 25 tCO_2e and 1 tonne of N_2O is 298 tCO_2e. The sources of GHG emissions in a farm can be diverse for the same gas (Figure 2), which sometimes complicates the analysis. GHG emissions have been divided into several main categories:

- Emissions related to the use of direct energy (fuel, gas….) and indirect energy (manufacturing of inputs).
- Emissions related to animals: enteric fermentation and manure management.
- Direct soil emissions (including CH_4 from rice cultivation), related to the spreading of nitrogen through mineral fertilizers, grazing, manure spreading and incorporated crop residues. Also, indirect emissions are estimated, corresponding to the atmospheric deposition and run-off and leaching of the nitrogen surplus of the farm.

In addition to the inventory of GHG gross emissions, ACCT offers:

- An estimate of the annual carbon storage variation of the farm resulting from the land use change (conversion of grasslands to cropland…), the establishment of best practices favourable to carbon sequestration (direct-seeding, cover crops) or the annual increase of wooded elements (hedges, vineyards, orchards…).
- An estimate of the GHG emissions avoided by the production on the farm of renewable energies replacing fossil energies (photovoltaic, wind, wood energy, biogas…). These renewable energies can be used directly on the farm or outside.

Results from ACCT

Energy and GHG global results at the farm level are the first results that users obtain. The objective is then to identify the main sources of energy consumption and GHG emissions on the farm. This detailed inventory is useful to locate overall issues on the studied farm and is a necessary step to ensure the relevance of improvement actions proposed later. Following the overall assessment at the farm level, the user can separate the energy consumption and GHG emissions into five different productions. This step is useful when the farm is diversified in its activities. The analysis of these distributions will help to show if one or several productions dominate in terms of energy consumption or GHG emissions. It is an essential support tool to decide which measures will help to reduce energy and GHG impacts from the farm.

As shown in Figure 3, there may be differences between the energy and the climate weight for the same agricultural production. Thus, the crops represent a small amount of the total energy consumption (7%) but are the second issue regarding the GHG emissions (19%). These analyses can then help to realise that different and complementary measures are sometimes necessary in the action plan to act simultaneously on the reduction of energy consumption and mitigation of GHG emissions.

Among the ACCT results, there are some indicators at the farm level to illustrate the intensity of the energy consumption (in GJ/ha[1] of UAA[2]) and GHG gross emissions

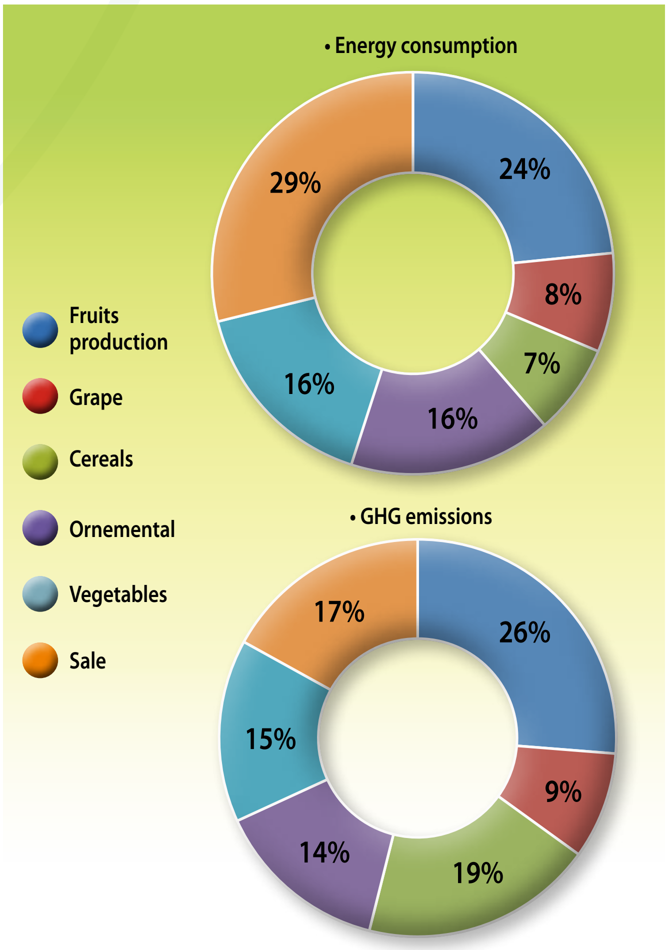


Figure 3: Example of a distribution of the total energy consumption and the GHG gross emissions per product for one diversified farm

(in tCO_2e/ha of UAA). For the product level analysis, a specific indicator per ha devoted to the production is generated in addition to indicators reflecting energy efficiency (in GJ/unit of product) and climate efficiency (in tCO_2e/unit of product). Based on these indicators, ACCT can compare the results of a farm or a product to a similar reference group. The objective of these comparisons is to identify the potential for improvement of the studied farm. For example, Figure 4 shows that the grain farm presents a low energy consumption per ha (-31% compared to the reference) as well as satisfying energy efficiency in GJ/tonne of dry matter (-8% compared to the reference). Thus, the prospects for progress potentially exist, but certainly with limits related to the proper energetic situation.

[1]Hectare.
[2]Utilised agricultural area.

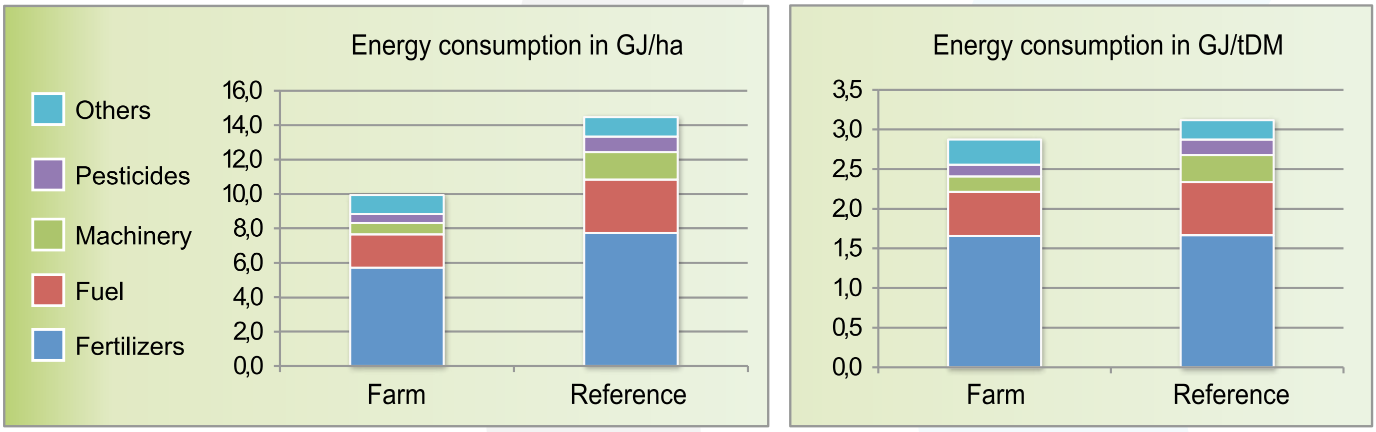


Figure 4: Example of a comparison of the energy performance of one cereal farm, per ha and per unit produced, with a reference group

ACCT also calculates a nitrogen balance at the farm level. It is based on the difference between the total nitrogen inputs on soils (fertilizers, animals, legumes…) and the amount of nitrogen exported from the soils (harvest…). The quantification of the nitrogen surplus of the farm allows assessing the overall balance of fertilization. There are often significant possibilities to reduce energy consumption and GHG emissions in case of a proved nitrogen surplus. Thus, the analysis of the surplus of nitrogen can potentially be useful to target if actions linked to the improvement of the fertilization should be proposed in the action plan.

Both for energy or GHG emissions, ACCT presents detailed tables of results at the farm or at the product level defined by the user upstream of the assessment. For example, Figure 6 details the quantities of GHG emitted per each specific source of emission (enteric fermentation, manufacturing of mineral fertilizers…). In this table, the emissions are also grouped in 3 scopes, distinguishing the origin of GHG emissions between those generated on the farm (scope 1), the indirect emissions related to energy (scope 2) and other indirect emissions (scope 3).

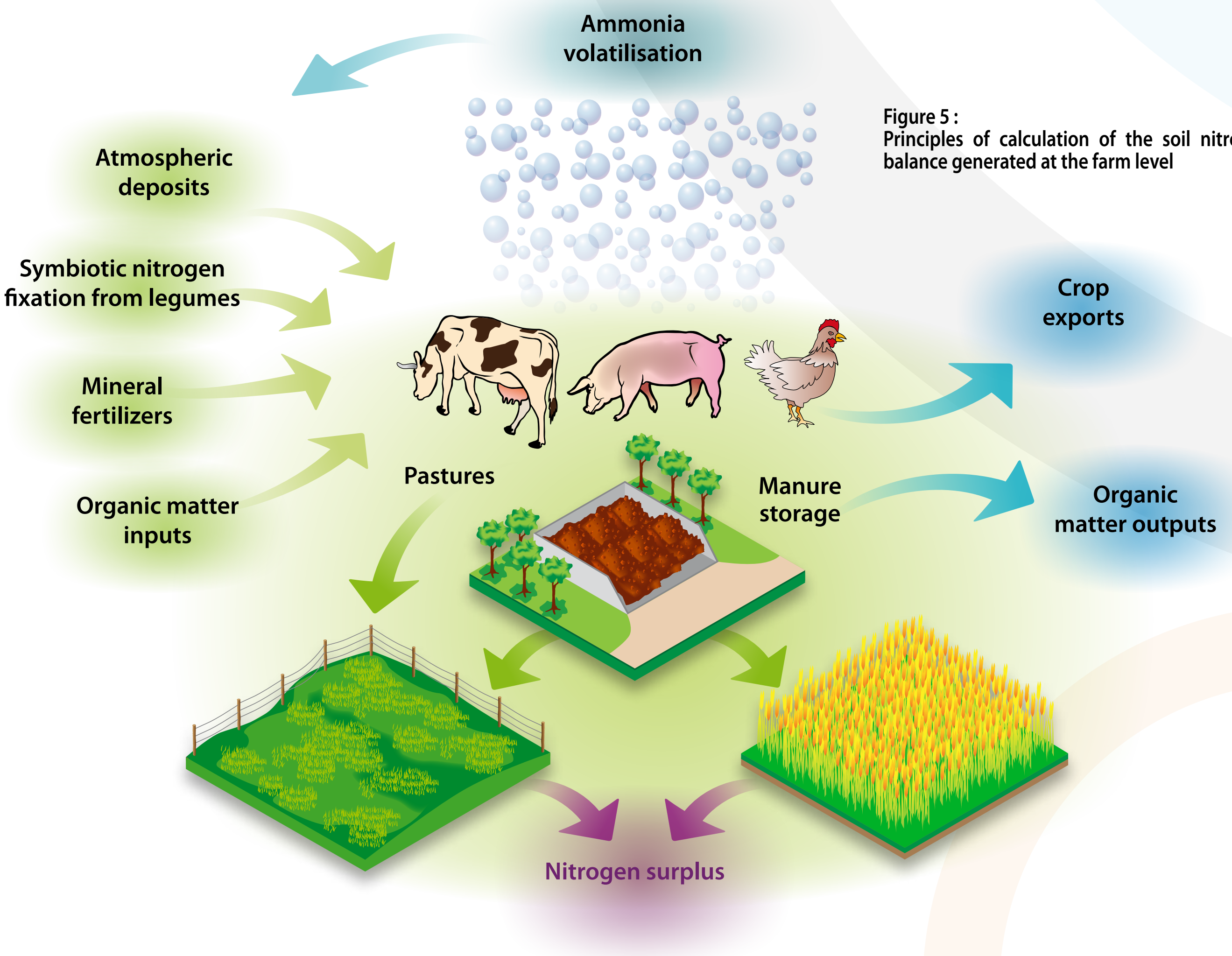


Figure 5 :
Principles of calculation of the soil nitrogen balance generated at the farm level

Current situation (tCO_2e/ year)	tCO_2	tCH_4	tN_2O	tonnes of halocarbons	tCO_2e	
Scope 1: Direct sources	50,22	8,36	0,93	0,00	530,55	46%
Machines and equipment:	45,96	0,00	0,00	0,00	45,96	4%
Mobile machines	34,14				34,14	3%
Fixed machines	11,83			0,00	11,83	1%
Process emissions:	4,26	8,36	0,93	0,00	484,59	42%
Enteric fermentation		3,07			76,86	7%
Manure management		5,28	0,29		217,17	19%
Direct emissions from soils			0,44		130,54	11%
Indirect emissions from soils			0,20		60,02	5%
Rice cultivation		0,00			0,00	0%
Scope 2: Indirect energy sources	17,72	0,00	0,00	0,00	17,72	2%
Electricity purchased	17,00				17,00	1%
Collective irrigation (electric pumping)	0,72				0,72	0%
Scope 3: Other indirect sources	676,86	0,00	0,00	0,00	608,14	53%
Mineral fertilizers (processing and transportation)	13,37		0,00		13,37	1%
Others crop inputs (seeds, pesticides)	4,22		0,00		4,22	0%
Plastics and others petrochemicals	1,15				1,15	0%
Feedstuffs purchased	567,05				567,05	49%
Others animal inputs (rearing costs, animals purchased...)	1,83				1,83	0%
Farm buildings and materials	10,36				10,36	1%
Machinery (and equipments)	4,20		0,00		4,20	0%
Transportations: employees	1,07				1,07	0%
Transportations: farming products	0,00				0,00	0%
Emissions from fuels manufacturing and transportation	73,59				4,88	0%
TOTAL tCO_2 / year	744,80	8,36	0,93	0,00	1156,42	100%

Figure 6: Example of a report of the annual flows of GHG at the farm level according to the ISO14064 and GHG Protocol format

Results from the diagnosis per farming systems

Various agricultural products

More than 120 farms have contributed to the references of energy and GHG, belonging to very diversified farming systems from 4 major European countries.

For the region of Valencia (Spain), the assessed crops were representative of the territory: oranges representing more than half of the irrigated surfaces, olives inland (mostly without irrigation) and rice, a small crop in terms of surface but fundamental towards the conservation of wetlands. In the region of Murcia (Spain), the assessments focus on fruit farms (peaches, tangerines, apricots, almonds…) as well as vegetables in fields or in greenhouses (lettuces, peppers, artichokes…). Finally, Tenerife island belonging to the Canary Island, was used to analyse the two main farming systems in terms of economic weight and surfaces: bananas (field or in greenhouses) and greenhouse tomatoes.

In Germany, farms all belong to the region of Baden Württemberg, in the south of the country. The dominant production is ruminants, cows for milk or beef, and apple production. A special feature for dairy cattle is the frequent presence of biogas plants, producing electricity and heat.

In Umbria, central Italy, the evaluations were conducted on diversified farms often representing the tradition and the agricultural vocation of this land: olive (extra virgin olive oil), quality wines, wheat, pork and beef but also farmhouse accommodation (Agriturismo) which is economically significant. Finally, the French farms are located mainly in the southwest in the Aquitaine and Midi-Pyrenees regions. There are breeding farms (dairy milk, beef, fat ducks…) as well as specialized crop farms (cereals, fruits…).

All these farms have participated **voluntarily** in this project. Thus, the results do not have a vocation of statistical representation but they are very useful regarding instruction and innovation in terms of energy consumption and GHG emissions.

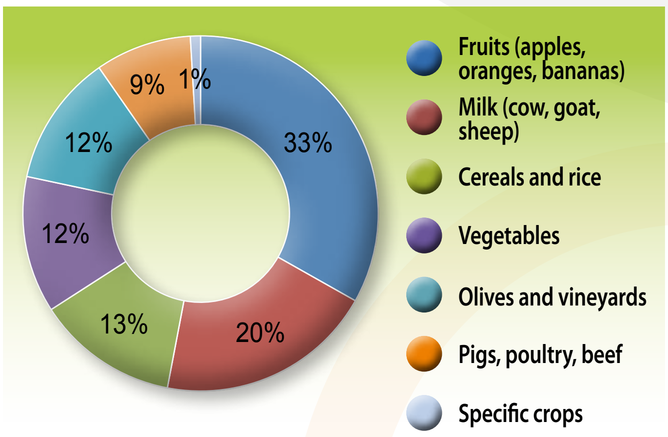


Figure1: Main farming systems in the *AgriClimateChange* network of farms

Bananas farms

	UAA (ha)	Yield (tonnes/ha)	Irrigation m^3/ha	Mineral nitrogen fertlization kg N/ha	Pesticides kg AM/ha	GJ/ha	GJ/tonne bananas	GHG tCO_2e/ha	GHG tCO_2e/t bananas
Average	5,85	51	9 445	265	46	68,25	1,35	10,99	0,22
Min	0,62	33	7 204	36	7	28,67	0,49	6,95	0,12
Max	13,30	60	14 003	527	169	146,76	4,49	17,20	0,42

Results for 9 bananas farms in the Canary Islands

These farms that produce bananas, with an average size of 5.85 ha and an average yield of 51 tonnes per ha, are fairly representative of the local farms. Most of the studied farms are in conventional farming (only one is organic). Depending on the orientation of the farm and its level of exposure to the wind, bananas can be grown under greenhouses (6 meters high, netting made of polyethylene) or sometimes outdoors. The irrigation system used is drip for all the farms. Once the bunch of bananas has been cut, the trunk of the plant is injected with an insecticide and then cut and crushed into the soil.

The evaluations highlight an energy consumption mainly due to irrigation (9,445 m^3/ha in average), fertilization (265 kg of mineral nitrogen per ha) and pesticides (46 kg of active matter/ha) used against pests and diseases. Most farming operations are manual, which explains the low impact of fuel. Issues in terms of global warming are centred on the nitrogen (soil emissions and manufacturing of fertilizers), which represents 75% of total emissions. On average, the energy consumption is 68.25 GJ/ha and the GHG gross emissions are 10.99 tCO_2e/ha.

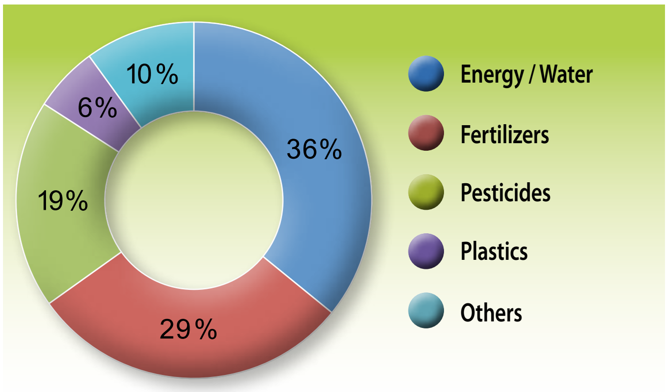
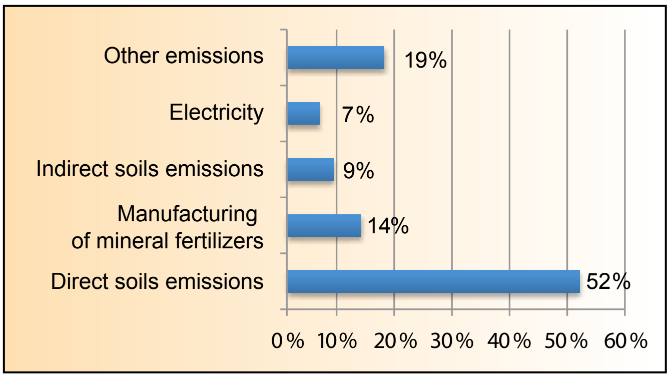


Figure 2: Main energy consumption



Sources of GHG emissions for bananas

Olives

	UAA (ha)	Yield (tonnes/ha)	Litres fuel /ha	Mineral nitrogen fertlization kg N/ha	Irrigation m^3/ha	Pesticides kg AM/ha	GJ/ha	GJ/tonne olive	GHG tCO_2e/ha	GHG tCO_2e/t olive
Average	2,87	3,0	157	35	1 134	2,0	29,05	9,79	1,93	0,65
Min	0,18	0,0	39	11	0	0,0	14,25	2,95	1,17	0,24
Max	11,00	5,6	2 534	209	1 145	7,6	58,36	19,45	4,38	1,47

Results for 16 olive farms in Spain and Italy

The common point of these 16 farms is that they are all specialised in olive production from traditional olive trees (low density, under 200 trees/ha).

4 organic farms are located in Italy, olives are transformed into olive oil on the farm. The average size is 9 ha.

12 conventional farms are located in Viver (Castellón region), half of them are non-irrigated and the other half are collective drip irrigated olive groves. The average surface is 0.91 hectares. The main energy consumption for olives are fuel with 36% (average consumption of 157 litres per ha) and electricity 22% (mainly through the processing into olive oil). Nitrogen fertilizers and packaging are minor issues with respectively 10% and 9% of the overall energy.

The main sources of GHG emissions are the fuel consumption for mobile machines in the fields (22%), fixed machines for processing (17%), electricity (13%) and the manufacturing of fertilizers (11%).

On average, the energy consumption is 29.05 GJ/ha and the GHG gross emissions are 1.93 tCO_2e/ha.

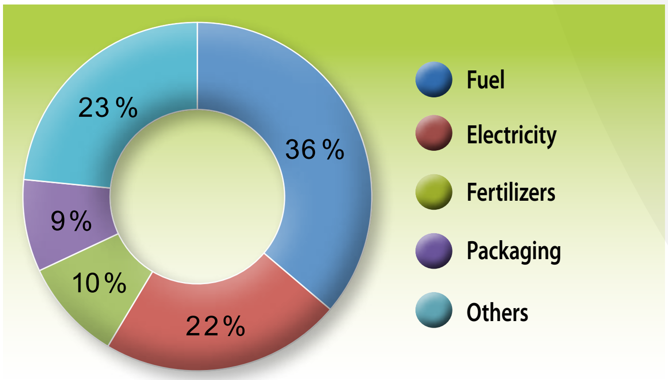
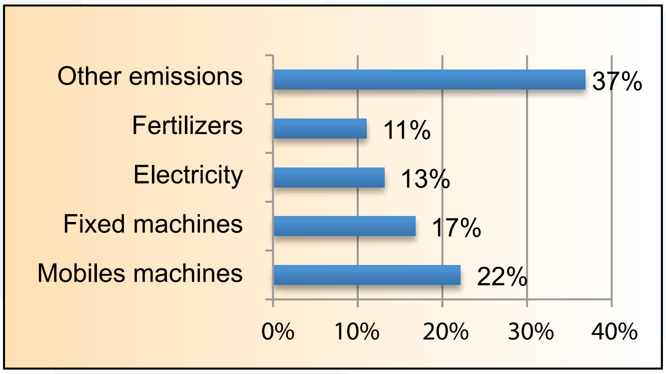


Figure 3: Main energy consumption



Sources of GHG emissions for olives

Fruit production

	UAA (ha)	Yield (tonnes/ha)	Litres fuel /ha	Mineral nitrogen fertilization kg N/ha	Irrigation m^3/ha	Pesticides kg AM/ha	GJ/ha	GJ/tonne of fruit	GHG tCO_2e/ha	GHG tCO_2e/t of fruit
Average	17,00	16,2	144	34	2 368	22,6	33,55	1,91	1,91	0,12
Min	0,75	1,6	42	0	80	0,0	3,78	0,61	0,24	0,04
Max	49,20	42,7	482	136	6 428	141,1	158,28	9,67	7,40	0,95

Results for 46 fruit farms in France, Germany and Spain

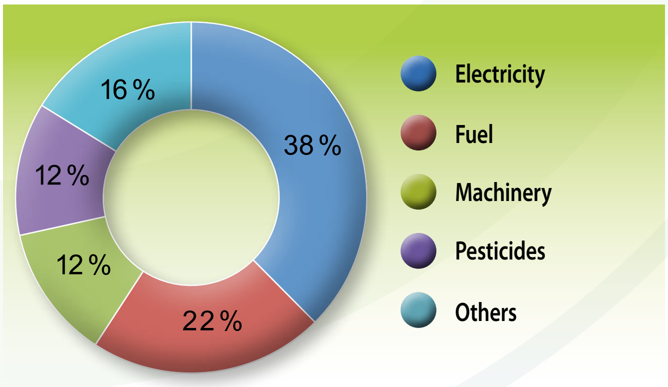
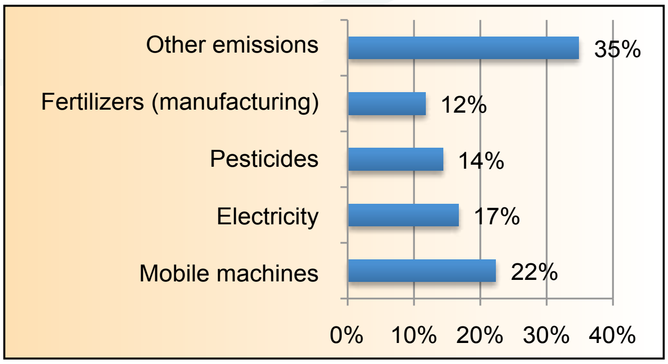


Figure 4: Main energy consumption



Sources of GHG emissions for fruit farms

These results include 46 fruits farms, mainly in conventional farming (only 4 in organic farming).

32 farms located near Murcia in Spain, produce apricots, peaches, pears and almonds with the systematic use of irrigation. The size of these farms can be highly variable (0.75 to more than 49 ha).

In Germany, 12 farms near the shores of Lake Constance mainly produce apples, sometimes accompanied by berries (blackcurrant…). These farms, whose size is often between 20 and 30 ha, are equipped with cold rooms to store the fruits. Finally, 2 farms located in the south west of France (around 20 ha of UAA), with the particularity of combining several fruit crops (plums, cherries, apples, peaches, apricots).

Only a few farms in Spain are characterized by a lower productivity (< 5 tonnes of fresh matter/ha), the average yield of the whole group is 16.2 tonnes of fresh matter/ha.

Regarding energy consumption, electricity (38%) emerges clearly. Its use is essentially linked to storage in cold rooms in Germany, while in Spain the use is restricted to irrigation (average of 2,368 m^3/ha). Then, comes fuel consumption (22%) for the mechanized operations in fields (144 litres/ha) as well as the pesticides representing respectively 12% of the total energy consumption of these farms.

In terms of GHG emissions, the first source of emission corresponds to mobile machines (22%), followed by electricity (17%) and pesticides (14%). Fertilization generally represents 20% when considering the manufacturing and the spreading on agricultural soils.

On average, energy consumption is 35.55 GJ/ha and GHG gross emissions are 1.91 tCO_2e/ha.

Almonds trees in the region of Valencia (Spain)

Fruit farm, region of Constance (Germany)

Vegetables under greenhouses

	UAA (ha)	Yield (tonnes/ha)	Litres of fuel/ha	Irrigation m^3/ha	kg AM/ha	Mineral nitrogen kg N/ha	GJ/ha	GJ/tonne vegetables	GHG tCO_2e/ha	GHG tCO_2e/t vegetables
Average	15,37	118	961	4 794	89	331	174,22	1,48	13,08	0,11
Min	1,60	56	382	2 500	8	96	120,04	0,73	10,12	0,05
Max	30,00	192	1 436	8 133	424	476	271,31	3,41	17,05	0,23

Results for 11 farms producing vegetables under greenhouses located in Canary Islands and Murcia

Most of the analysed farms produce tomatoes in the Canary Islands under integrated agriculture schemes for exportation, mainly to the UK. These farms are quite large (average size of 15 ha) and intensive with a high level of machinery per ha, they require a lot of staff (30-50 workers per hectare) and the irrigation and fertilization levels are adjusted automatically by a computerised mechanism, which allows a high uniformity in the farm. The tomato farms on the Canary Islands are managed on a 7-8 month cycle, starting in September-October with an average productivity of 118 tonnes per ha. Tomatoes are mostly cultivated in the ground even if artificial substrates also exist. The crop residues are usually exported out of the greenhouse for sanitary conditions.

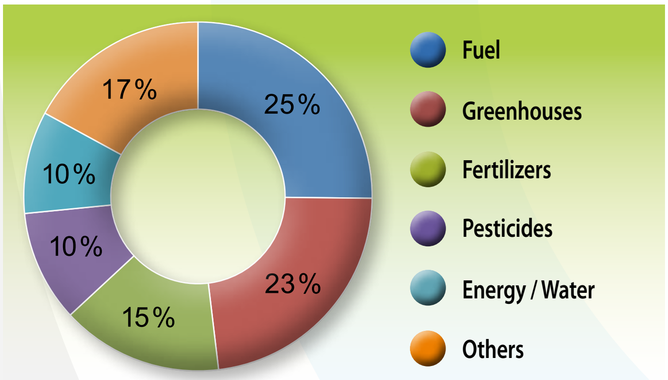
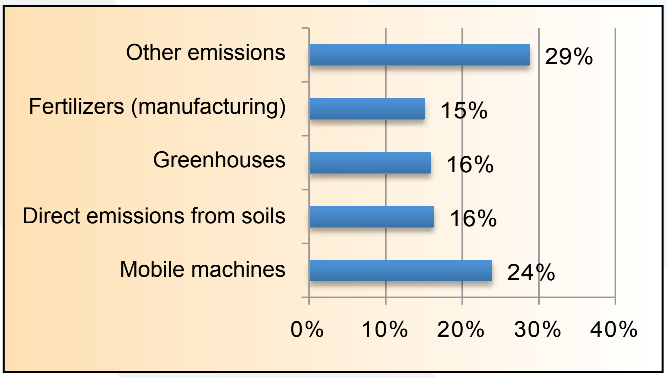


Figure 5: Main energy consumption



Sources of GHG emissions for vegetables under greenhouses

Peppers cultivated in greenhouses

Four farms, located in the region of Murcia, produce peppers. The type of farming is comparable to the tomatoes from the Canary Islands (same type of greenhouse and full coverage).
It is important to note that none of these greenhouses are heated.

The main energetic issues for vegetables under greenhouse are fuel consumption (961 litres per ha), the manufacturing of greenhouses (structure and plastic) as well as mineral nitrogen (331 kg of N/ha) and pesticides applied.
On the other hand the GHG emissions from fertilization (manufacturing and spreading) are the main issue (31%), before fuel for machinery (24%) and greenhouses (16%).
The energy consumption (174 GJ/ha) as well as the GHG emissions per ha (13 tCO_2e/ha) reflect the intensity of this farming system. Nevertheless, room for improvements exist looking at the diversity of the results inside the group.

Field vegetables

	UAA (ha)	Yield (tonnes/ha)	Litres of fuel/ha	Irrigation m^3/ha	kg AM/ha	Mineral nitrogen kg N/ha	GJ/ha	GJ/tonne vegetables	GHG tCO_2e/ha	GES tCO_2e/t vegetables
Average	19,40	34	45	2 716	6	116	19,01	0,57	2,29	0,07
Min	8,00	13	19	2 480	1	46	12,63	0,31	0,97	0,04
Max	33,00	41	120	6 120	25	155	31,99	1,34	3,48	0,17

Results for 10 field vegetables farms in Murcia

The results relate to 10 farms in the region of Murcia (Spain), all specialized in the production of field vegetables in conventional agriculture. Generally, one type of vegetables is produced per farm: broccolis, lettuces or artichokes. The average size of these farms is 19.4 ha with an average production of 34 tonnes of fresh vegetables per ha. These farms all use irrigation with an average consumption of 2,716 m^3/ha.

The average energy consumption of these field vegetables farms, with 19.01 GJ/ha of UAA, is much lower than the one from farms producing vegetables under greenhouses (174.22 GJ/ha), for an energy efficiency (energy consumption per tonne of vegetables) also more favourable to the field vegetables.

The main source of energy consumption is fertilization (44%), with an average amount of 116 kg of mineral N/ha, followed by electricity for irrigation (22%), fuel for traction (11%) and at last machinery (10%).

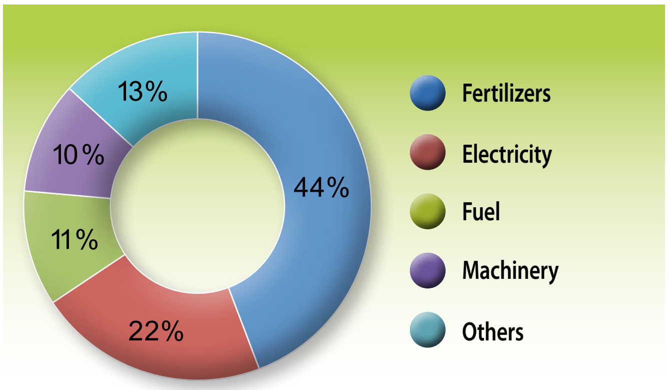
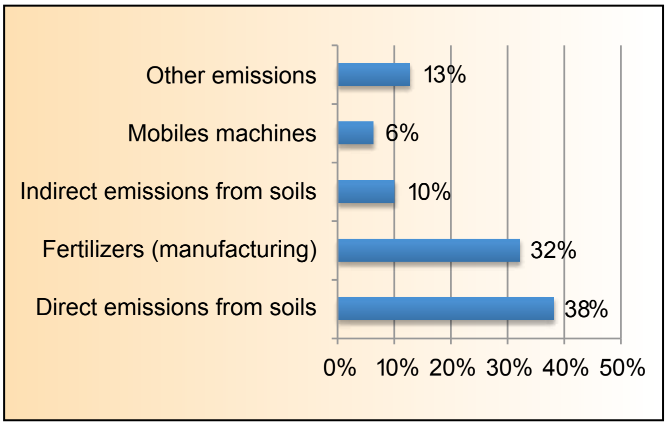


Figure 6: Main energy consumption



Sources of GHG emissions for field vegetables

GHG emissions from field vegetables farms are also lower per tonnes of vegetables than the ones from vegetables farms under greenhouses (2.29 tCO_2e/ha versus 13.08 tCO_2e/ha). Fertilization (manufacturing of fertilizers, spreading on soils and nitrogen excess) represents 80% of the total GHG emissions. Finally, emissions due to mobile machines (tractors) are 6%.

Vegetable field production (Spain)

Vineyards

	UAA (ha)	Yield (tonnes/ha)	Litres of fuel /ha	Mineral fertilizers kg N/ha	Electricity kWh/ha	Pesticides kg AM/ha	GJ/ha	GJ/tonne grapes	GHG tCO_2e/ha	GHG tCO_2e/t grapes
Average wine	8,67	6,2	520	19	788	16	54,51	8,75	3,71	0,60

Results for 3 farms producing wine in Italy

The results touch on 3 farms making wine in addition to the cultivation of grapes, located in the centre of Italy (Umbria). The average size is 8.67 ha. One of these farms uses organic farming, whereas the other two are conventional.

The main energetic issues of these farms concern agricultural fuel (39%) for the vineyards operations (520 litres of fuel/ha), the different types of packaging used for the wine (28%), electricity (17%) related to winemaking cellar (126 kWh/tonne of grapes) and pesticides applied on the vineyards (5%).

The climate impact of these vineyards mainly concerns the mobility of the agricultural machinery (37% of the total GHG emissions), wine packaging (36%) and electricity used (9%).

On average, the energy consumption is 54.51 GJ/ha and the GHG gross emissions are 3.71 tCO_2e/ha.

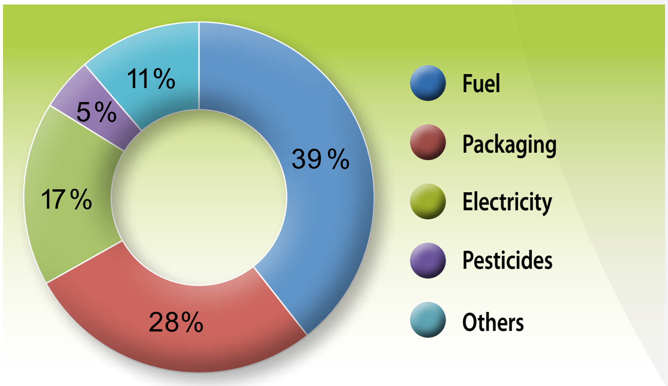
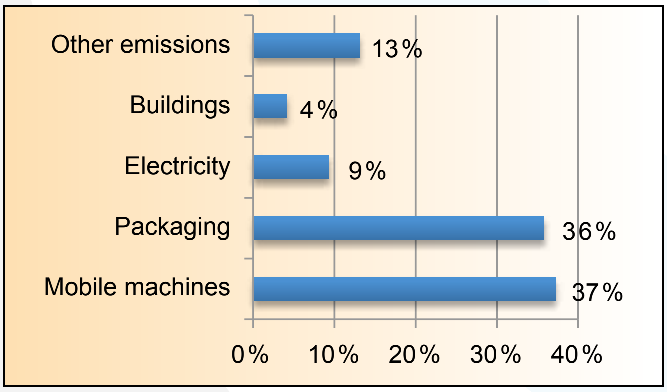


Figure 7: Main energy consumption



sources of GHG emissions for wine farms

Crop farms

	UAA (ha)	% Crops/UAA	Yield (tonnes MS/ha)	Litres of fuel/ha	Mineral nitrogen kg N/ha	Pesticides kg AM/ha	GJ/ha	GJ/tonne DM	GHG tCO_2e/ha	GHG tCO_2e/t DM
Average	126,92	91%	3,2	121	92	1,5	17,94	6,20	1,90	0,66
Min	26,50	62%	1,3	44	0	0,0	6,46	2,54	0,66	0,27
Max	520,00	100%	5,2	221	160	5,0	33,59	22,79	3,29	1,57

Results for 19 crop farms in France and Italy

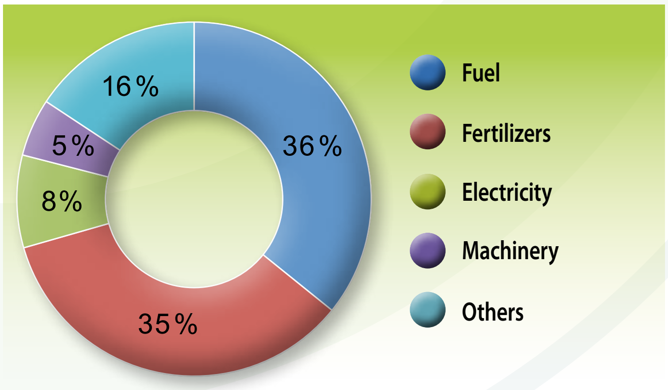
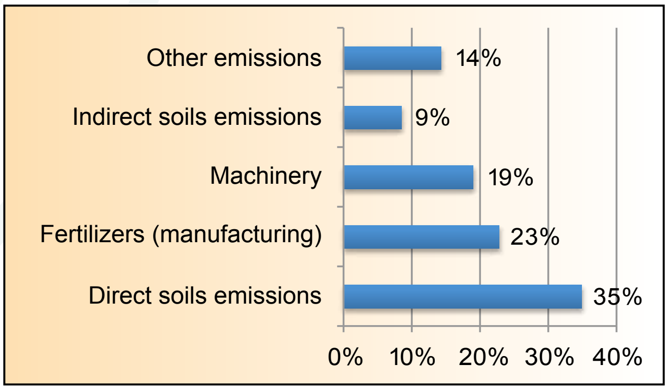


Figure 8 : Main energy consumption



Sources of GHG emissions for crop farms

Photo: Eric Péro (spyro)

The results touch on 10 farms specialized in crops (cereals and protein-oil crops) located in the south west of France (2 are organic) and 9 crop farms in the Umbria region in Italy (2 are organic), whose the main economic activity is cereals (62 to 83% of the UAA) usually associated with other more secondary production (vineyards, olives or vegetables). The average size is 126 ha, although the sample includes very different dimensions of farms (26 ha to over 500 ha of UAA). Irrigation is practiced only on 6 farms and is generally limited to less than 20% of the total UAA of the farm.

Agricultural fuel and mineral fertilizers represent the two main sources of energy consumption of the crop farms, each with about 35% of the total energy consumption. The average fuel consumption is 121 litres/ha but can vary depending on the crop management style used to establish the crop (full, reduce or no-tillage). Apart from 4 organic farms, all the rest spread mineral fertilizers on the crops, in average 92 kg of N/ha. Electricity, mainly for irrigation, represents 8% of the total energy consumption and the agricultural machinery 5%.

The GHG impact is strongly related to the fertilization (manufacturing, spreading on soils and nitrogen excess) with 67% of the total GHG emissions. Emissions related to the operation of agricultural machinery represent 19% of the total GHG emissions.

On average, energy consumption is 17.94 GJ/ha and the GHG gross emissions are 1.90 tCO_2e/ha.

Rice cultivation

	UAA (ha)	Yield (tonnesMS/ha)	Litres of fuel/ha	Mineral nitrogen kg N/ha	GJ/ha	GJ/tonne rice	GHG tCO_2e/ha	GHG tCO_2e/ tonne rice
Average	11,35	5,5	90	86	12,80	2,34	5,07	0,93
Min	1,24	4,2	48	59	9,74	1,97	4,54	0,66
Max	39,00	9,3	120	210	23,42	3,73	6,91	1,11

Results for 8 farms cultivating rice in the natural park of Albufera (Valencia, Spain)

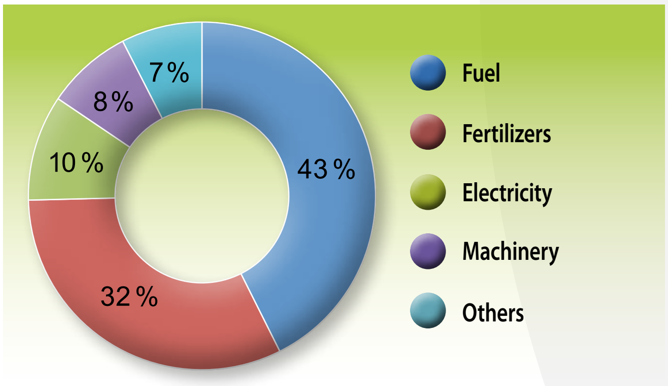
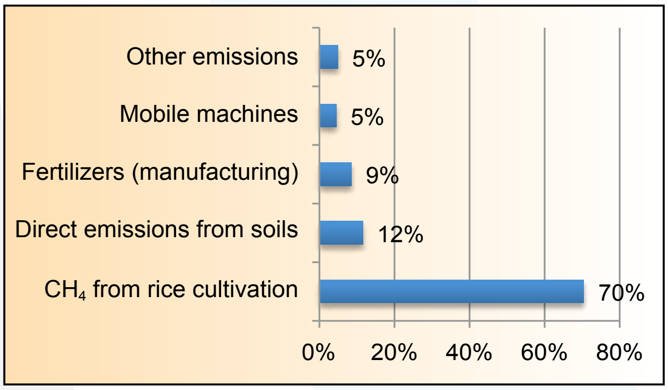


Figure 9 : Main energy consumption



Sources of GHG emissions for rice cultivation

The average farm size that is growing rice is 11.35 ha. For Bomba variety, the usual yield is around 5.0 tonnes/ha but is higher (9,5 tonnes/ha) for J. Sendra and Gleva varieties. The type of farming is conventional for all the farms, using two different irrigation systems: electric pumping for flooding and evacuating water, or water management by gravity.

Energy consumption related to fertilizers is the most important consumption (43%). However, the quantity applied per ha depends on the productivity of the rice variety grown: average of 177 kg N/ha for J.Sendra and Gleva and 69 kg N/ha for Bomba. Fuel consumption (32%) is also important, as rice cultivation requires diverse works and operations on flooded soils (average fuel consumption of 90 liters/ha). The machinery used is specialized and powerful for such small plots, something that explains that it represents 10% of the total energy consumption of the farms. Electricity consumption represents 8% of the total energy spending for all the farms but it can vary between 0% when managing water with gravity to 11% for farms using electric pumping system for flooding and evacuating water.

GHG emissions are mainly related, as expected for rice farms, to methane soil emissions (70%) and direct emissions (nitrous oxide) from soils (12%). Methane emissions are linked to the flooding practices, as flood periods are combined with organic matter and crop residues that provide ideal conditions for methanogenesis, and the vast majority of this methane is released to the atmosphere. Nitrogen fertilization contributes to 21% of the total GHG emissions, divided in 12% of direct emissions from soils and 9% from manufacturing of mineral fertilizers.

Dairy milk

	UAA (ha)	Nb cows	Milk litres/ cow	Milk production (litres)	kWh/cow	% autonomy concentrates	GJ/ha	GJ/1000 litres milk	GHG tCO_2e/ ha	GHG tCO_2e/1000 litres milk
Average	88,54	51	5 941	301 988	643	15%	23,66	6,94	5,00	1,46
Min	30,00	20	2 000	40 000	282	0%	6,68	3,33	1,96	0,80
Max	175,00	141	8 135	1 049 463	1246	100%	84,33	33,80	9,80	2,96

Results for 24 farms producing dairy milk in France and Germany

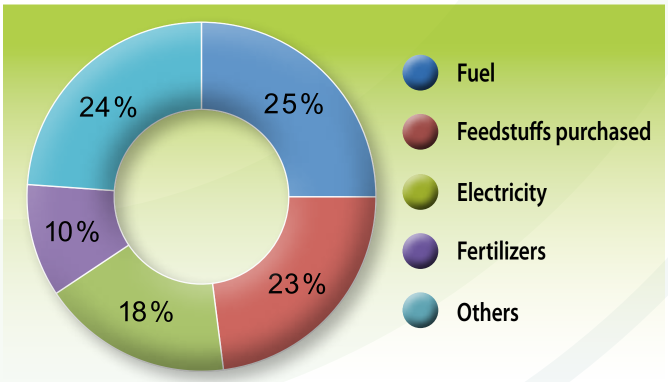
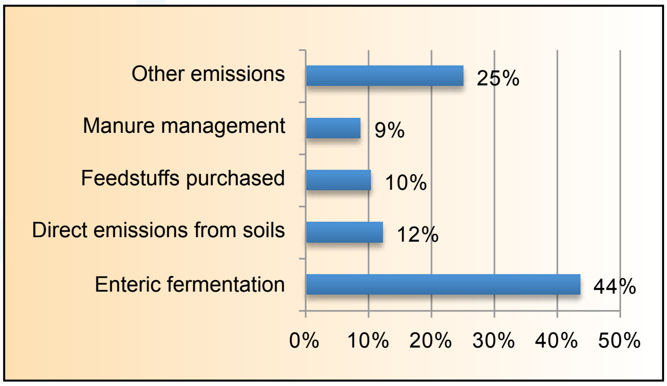


Figure 10: Main energy consumption



Sources of GHG emissions for dairy farms

The results touch on 24 dairy farms, 11 organic and 13 conventional. 15 farms are located in the region of Lake Constance, and 9 in the south west of France. The average size of these farms is 88.54 ha for 51 cows producing 5,941 litres/cow/year. However, this group includes contrasting milk productivity levels, between 2,000 and 8,000 litres/cow/year. In Germany, dairy farms are often equipped with biogas plants, thus it is the case for 6 out of 15 farms in the group. Finally, the autonomy in feedstuffs of these farms is frequently low (15% in average), only 2 farms are distinguished with more than 85% of autonomy.

Three sources of energy consumption stand out: agricultural fuel (25%) whose use concern field management as well as animal care in buildings, feedstuffs purchased (23%) related to the low livestock autonomy for concentrates and electricity (18%) whose main use is the operating of the milking parlour (average of 643 kWh/cow/year). The fertilizers purchased represent 10% of the total energy consumption (important part of organic farms in the sample).

The main GHG emission of these dairy farms is enteric fermentation from ruminants (44%). Direct emissions from agricultural soils (12%) correspond to all the nitrogen sources applied (pasture, manure, mineral fertilizers). Feedstuffs purchased represent 10% of the total GHG emissions and manure storage 9%. Note that the presence of grasslands in the UAA, causing additional carbon storage in the soils, can have a significant impact at the farm level (compensation of 30 to 40% of the total GHG emissions).

On average, the energy consumption is 23.66 GJ/ha and the GHG gross emissions are 5.00 tCO_2e/ha.

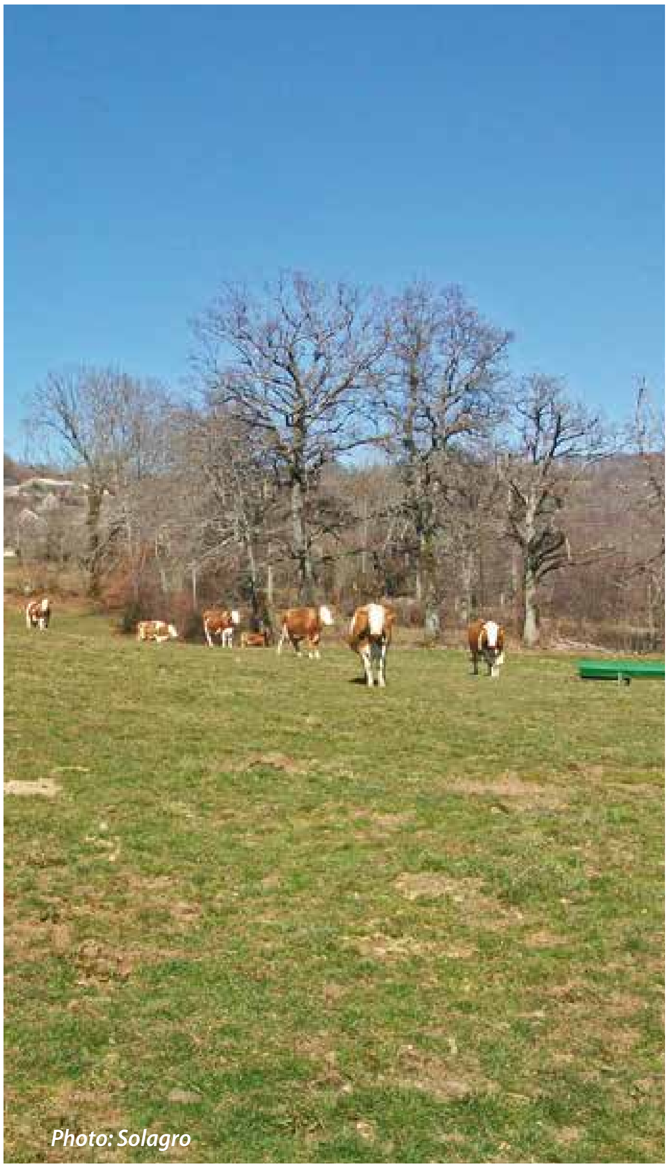


Photo: Solagro

Beef production

	UAA (ha)	Quantity live meat (kg)	Live meat kg/ha	% Autonomy concentates	kg concentrate/ kg live meat	Litres fuel/ha	GJ/ha	GJ/tonne live meat	GHG tCO_2e/ha	GHG tCO_2e/ tonne live meat
Average	53,24	145 040	341	55%	4,50	130	16,78	49,29	7,24	21,25
Min	27,80	3 940	61	0%	0,00	30	4,90	29,25	2,20	10,76
Max	64,73	44 000	688	93%	6,78	325	27,64	138,44	20,22	40,57

Results for 8 farms producing beef in France, Germany and Italy

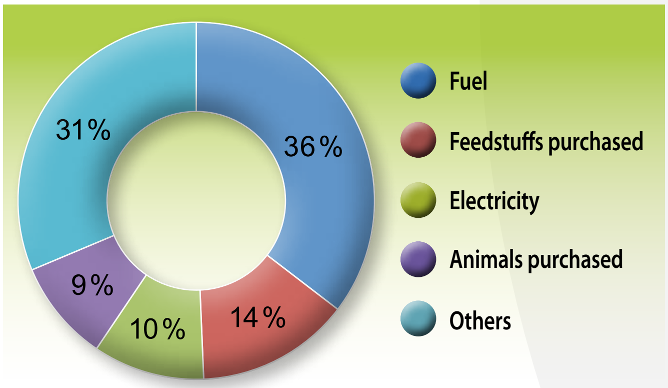
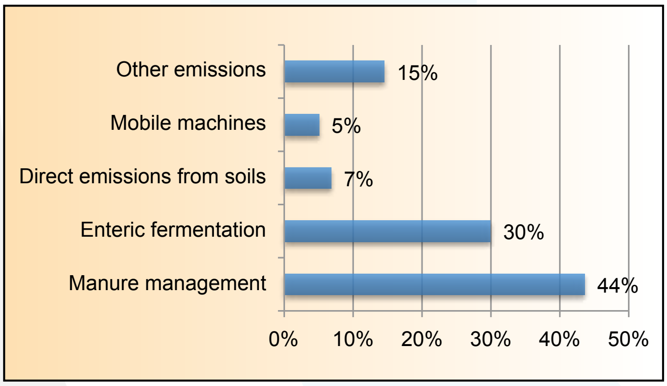


Figure 11: Main energy consumption



Sources of GHG emissions for beef farms

The results touch on 5 farms in Italy (Umbria), 2 in Germany and 1 in France. The average size is 53.24 ha. These farms usually have suckling cows in the herd, except 2 specialized in the fattening of young cattle. The autonomy in feedstuffs of the farm is extremely variable depending on the farms. There are two distinct groups of farms, heavily dependant (-12% of autonomy) or lightly dependant (more than 80% of autonomy).

The main source of energy consumption is agricultural fuel (36%), with an average of 130 litres of fuel/ha. Feedstuffs purchased (14%) with an average of 4.5 kg of concentrate/ kg of live meat, then electricity (10%) and the young animals purchased (9%).

The main GHG emissions are related to animals, manure storage representing 44% of the total GHG emissions and enteric fermentation 30%. Nitrogen applied on agricultural soils represents only 7% of the total GHG emissions and the operating of agricultural machinery 5%.

On average, the energy consumption is 16.78 GJ/ha and the GHG gross emissions are 7.24 tCO_2e/ha.

Photo: Solagro

Pork and poultry meat

	UAA (ha)	Quantity live meat (kg)	% Autonomy concentates	kg concentrate/kg live meat	GJ/ha	GJ/tonne live meat	GHG tCO_2e/ha	GHG tCO_2e/t live meat
Pork, average	66,09	856 250	29%	2,21	53,48	16,51	6,90	2,13
Poultry, average	62,56	760 337	8%	1,83	57,53	33,13	4,28	2,47

Results for 4 pork farms and 7 poultry farms

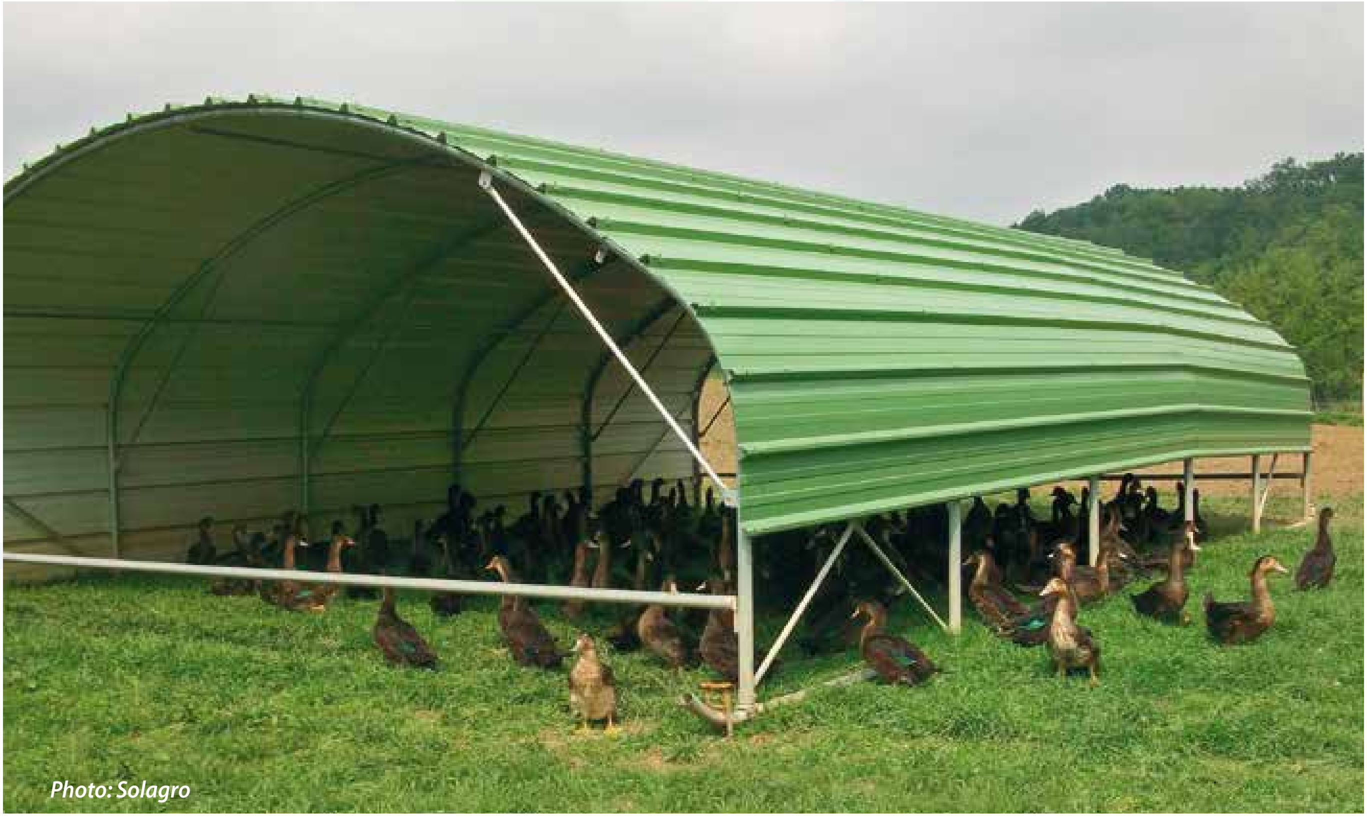


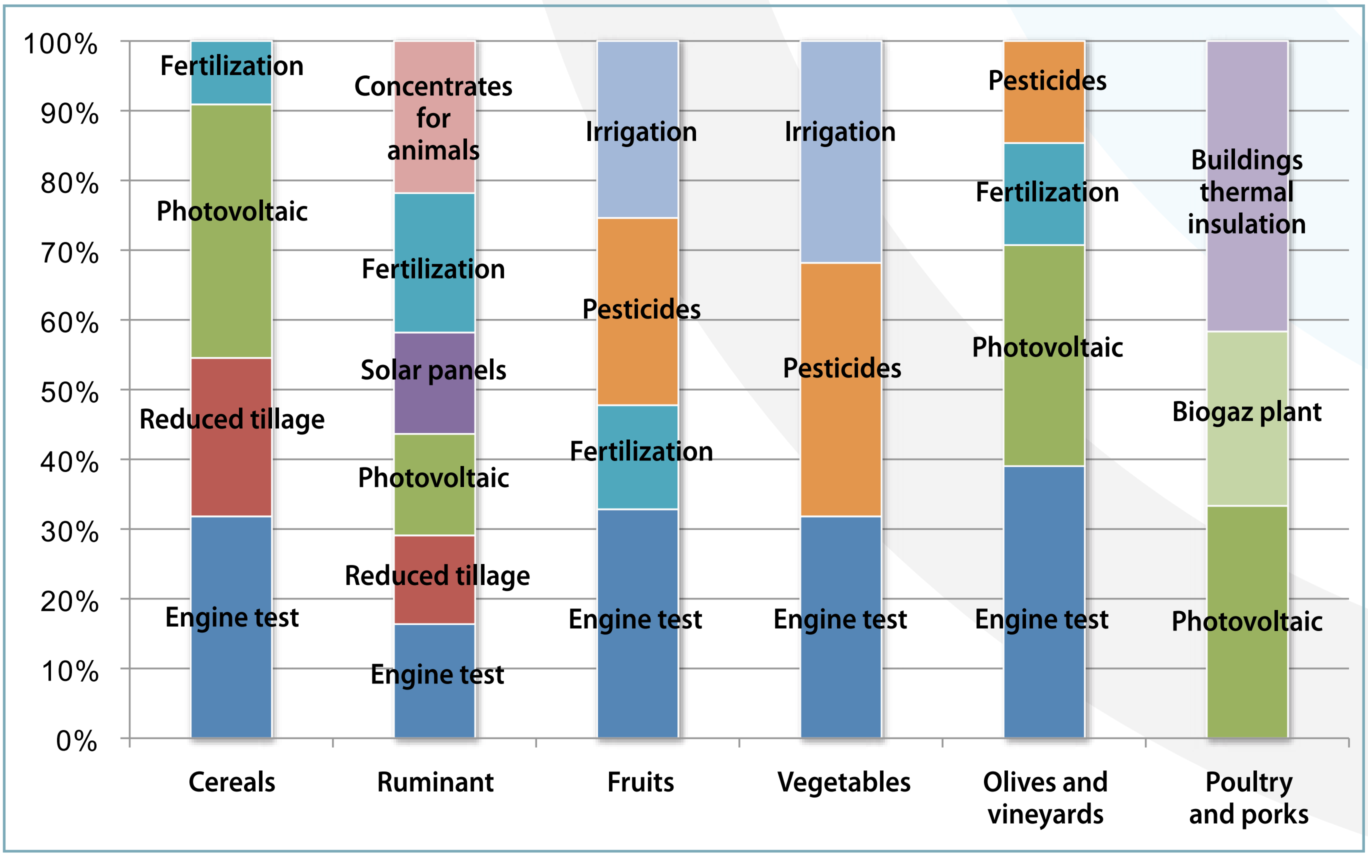
Photo: Solagro

The results for pork touch on 4 conventional farms located in Germany (3) and France (1). A part of the concentrates is usually produced on the farm (average autonomy of 29%) for a total consumption of 2.21 kg of concentrates per kg of live meat.
Also, 7 farms producing poultry (fat ducks or broilers), located mainly in France (1 farm in Italy). The autonomy of concentrates is extremely low (8% in average).

For pork production, the energy consumption is on average 53.48 GJ/ha and the GHG gross emissions are 6.90 tCO_2e/ha. The main sources of energy consumption are feedstuffs purchased (29%), electricity (26%) for the operation of breeding buildings (consumption of 1,487 kWh/sow), agricultural fuel (15%) and mineral fertilizers (8%). The main sources of GHG emissions are the feedstuffs purchased (37%), emissions from agricultural soils (15%), manure storage (12%) and the operating of agricultural machinery (7%).
For poultry, the energy consumption is on average 57.53 GJ/ha and the GHG gross emissions are 4.28 tCO_2e/ha. The main sources of energy consumption are electricity (29%), feedstuffs purchased (15%), gas (14%) for the heating of animal buildings and the agricultural fuel (10%). The main sources of GHG emissions are emissions from agricultural soils (17%), feedstuffs purchased (16%), the operating of agricultural machinery (11%) and the manufacturing of mineral fertilizers (9%).

Action plans: measures to reduce energy and GHG emissions

The individual assessments of the 120 farms of the European network put forward the main energetic and climatic issues. On this basis, each partner worked on the implementation of an action plan for each situation, aiming at getting a significant reduction (between 10% and 40%) for energy and GHG emissions.
The action plans generally combine several measures, **on average 4 actions** per farm, from a total of more than 45 different actions across the 4 countries participating in the *AgriClimateChange* project. Unlike other sectors, the particularity of agriculture is that a significant part of the GHG emissions is not related to energy consumption (N_2O, CH_4). Also, the fight against climate change can be achieved both through mitigation of GHG emissions and through carbon sequestration. Opportunities also exist on farms to produce renewable energies (solar, biomass…). Thus, to achieve a significant reduction potential on the energy and GHG issues, complementary measures have to be suggested to the farmers.



Frequency of the main measures proposed in the action plans per farming systems

The proposed measures can be classified under 4 main categories: agronomy, livestock, energy (fossil and renewable) and carbon sequestration. Inside these measures, some of them concern the optimisation of agronomic practices or livestock (optimisation of the fertilization, adjustments of the amount of concentrates distributed to animals…), others may require some investment for their implementation (boiler with biomass, biogas plant…). Similarly, some actions can be implemented in a short to medium term, while others, sometimes very structured at the farm level, require an investment of time and a clear interest from the farmers for their implementation (no-tillage, diversified crop rotation, change in the fodder system for breeding…).

More than half of the measures proposed to the farmers across the 4 countries have been implemented during the *AgriClimateChange* project, in connection with the farmer's motivations, the economic and regulatory context (CAP…), opportunities for investment subsidies… Generally, farmers are more sensitive to measures that allow energy reductions than GHG reductions, due to the economic gain that is often associated to them. The main obstacles identified in the implementation of measures are frequently economic (no national investment subsidies program, high selling prices for cereals insensitive to the reduction of nitrogen excess…) or possibly technical (insufficient technical advice, high risk-taking for the farmer due to the absence of support).

Agronomy

Nitrogen balance
Reduced tillage
Long rotation
Presence of legumes
Cover crops
…

Livestock

Efficient equipment for the milking parlour
Insulation of heated livestock building (pork, poultry)
Optimisation of the feedstuffs distributed
Development of grazing
Solar dryer for fodder
…

Carbon storage

Grassland farming systems
Direct-seeding
Cover crops
Implantation of hedges
Agroforestry
…

Fossil and renewable energie

Solar photovoltaic and thermal
Biogas
Biomass
Engine test
Economical driving
…

• Example of types of reduction measures included in the action plans •

The energy and GHG results from the evaluations show that there are sometimes significant differences between farms belonging to the same farming system. Thus, a factor 3 to 5 is regularly observed in all the farming systems for the indicators energy consumption per ha and GHG emissions per ha between the extreme values (minimum and maximum) for a same group. This shows margins of progress that are not the same related to the farms. However, the action plans proposed to the farmers have regularly helped to identify a potential of reduction in response to the initial objective of between 10% and 40%.
The tables below present an overview of the types of actions proposed for the 4 main categories of measures. Finally, the coming chapter offers a detailed presentation of case studies illustrating the different farming systems in the European network of farms to highlight the benefits of different actions implemented.

Agronomy

Action	Objective	Gains Energy – GHG - Economic	Feasibility
Nitrogen Balance	Determine realistic crop yields objectives in order to reduce mineral fertilizers applied	+++ Nitrogen surplus has to be under 50 kg of N/ha	Technical advice Short term
Soil tillage reduction – direct-seeding	Reduce fuel consumption compared to conventional field management with ploughing	+++ Energy and economic gains, lower GHG impact Reduction Potential for fuel between 20% and 40%	Technical advice (Investment only in case of direct- seeding) Short to medium term (long term in case of direct-seeding[1])
Introduction of leguminous in grasslands and croplands	Leguminous, through symbiotic nitrogen fixation, can enhance the soil fertility, reduction of the dependency of mineral fertilizers	++ >10% of leguminous surfaces in cereals >40% of leguminous surfaces in temporary grasslands	Technical advice Short to medium term
Cover crops	Recycle nitrogen surplus at the end of the crop cycle for the following crops	++ No bare soil in winter Reduce risk of water pollution and soil erosion	Technical advice Short to medium term
Optimizing water for irrigation	Reduction of electricity consumption, control of the amount through tools that help to decide (Irrigation sensors…)	Energy and economic gains Essential for farms with a significant proportion of irrigated surfaces	Investment Short term
Reduction of seeding density	Possible reduction of nitrogen needs of the crops and reduced sensitivity to fungal diseases	+ Energy and economic gains Applicable on all cultivated cereals	Technical advice Short term

[1] direct-seeding has to be combined with a diversified crop rotation to be successful

Carbon sequestration

Action	Objective	Gains Energy – GHG - Economic	Feasibility
Grassland farming systems	Maintain and strengthen the carbon stored in grassland soils	+++ Sequestration potential on all farms with ruminants	Technical advice Short term
Direct-seeding combined with cover crops	Increasing of the organic matter content in cropland	+++ Sequestration potential on all croplands	Technical advice Medium term
Implantation of hedges	Enhance agro-ecological infrastructures on farms, possibility of biomass valorisation	+ Numerous environmental benefits	Technical advice, investment Short term
Agroforestry			Technical advice, Investment Medium term

Energy savings and renewable energies

Action	Objective	Gains Energy – GHG - Economic	Feasibility
Solar photovoltaic and thermal	Enhance the roof surfaces for the production of electricity or renewable hot water	++ High variability of the price per kWh between countries	Investment Short term
Biogas	Avoid GHG emissions from manure, better control of fertilization, renewable energy production	Energetic gains even more important if the heat generated is recovered Manure from bovine and porcine farms generally suitable	Investment Medium term
Biomass	Possible fuel replacement per biomass produced on the farm	++ Potential linked to the importance of heat needs	Investment Short to medium term
Renewal of old equipment	Improve the energy performance of equipment (tractors, electric motors…)	++ Significant potential in case of old tractors or old electric motors	Investment Short to medium term
Setting tractors and economical driving	Check the tractor's performances and give advices to optimize fuel consumption	++ Requires the proximity of a collective mobile engine test for tractor	Technical advise, Training Short term

Livestock

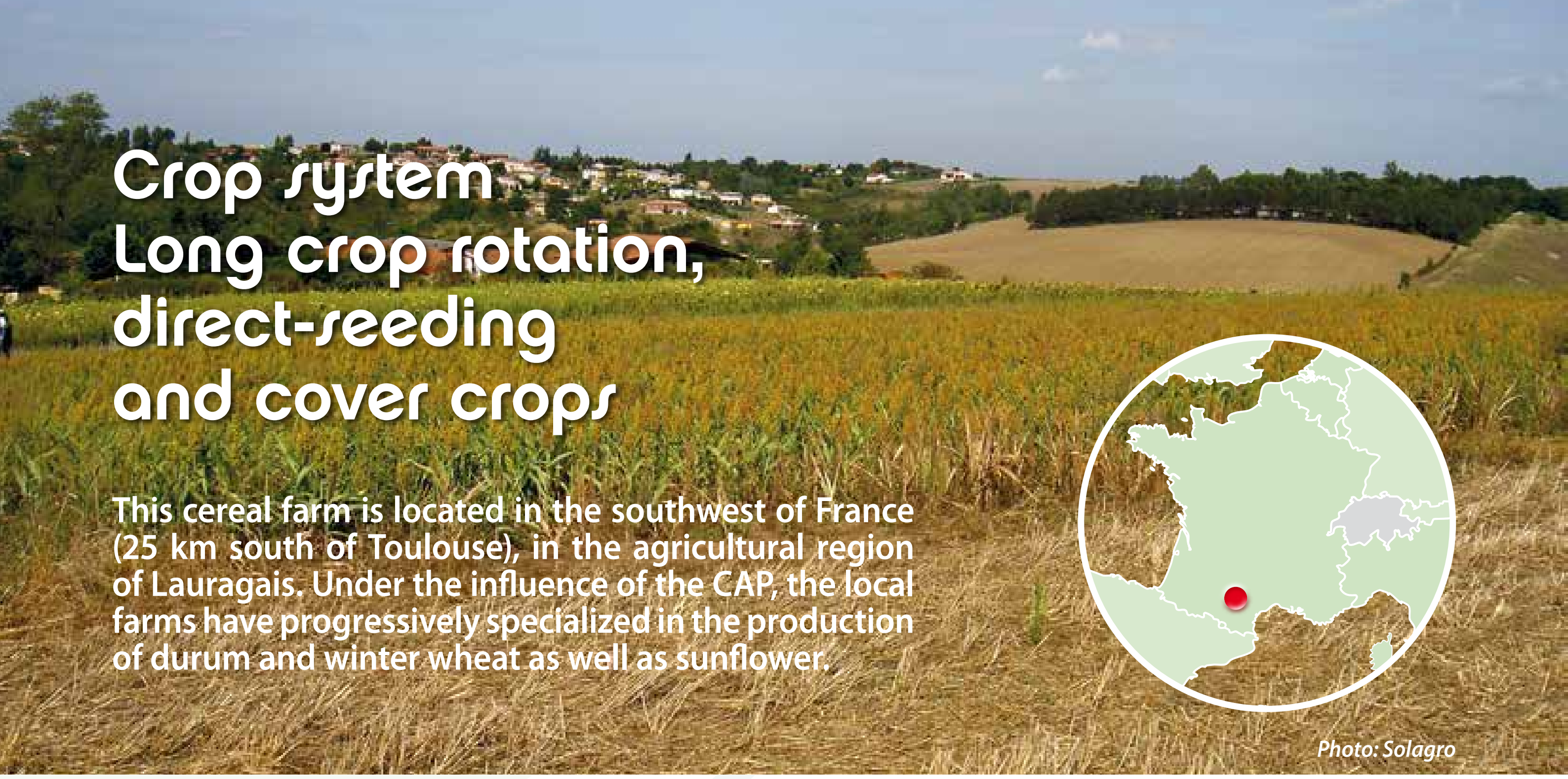
Action	Objective	Gains Energy – GHG - Economic	Feasibility
Efficient equipment for the milking parlour	Decrease electricity consumption: heat recovery on the milk tank, pre milk cooler, vacuum pump	+ GHG gain linked to the national emission factor and economic gain linked to the national price of the kWh	Investment Short term
Insulation of heated livestock buildings	Decrease gas or electricity consumption	Energy and economic gains Important potential in case of old buildings	Investment Short term
Quantities and type of concentrates distributed to the animals	Optimize the quantities distributed (avoid waste), prefer less energetic concentrates (replacement of soya per rapeseed)	++ Frequent reduction potential on farms with animals	Technical advice Short term
Development of grazing	Provides a more sober energy farming system (less fuel, concentrates,machinery…)	++ Valorisation of grasslands near farm buildings	Technical advice Medium term
Solar dryer for fodder	Improve the nutritional quality of the fodder distributed to the animals	++ Important reduction potentiel of feedstuffs purchased	Investment and technical advice Medium to long term

Case studies
Crop systems

The levers to reduce energy impact and GHG emissions are mainly agronomic measures. Fuel and fertilizers are central issues and there are several possible mitigation measures, illustrated and quantified through three different examples:

- First in France, a crop farm that has combined an increase in the number of crops in the pattern system, direct-seeding and cover crops.
- In Spain, rice cultivation presents some common problems with crop systems but also a few specificities related to the flooded plots.
- Finally in Italy, the use of GPS technology on a specialized farm in crops to optimise inputs, including fuel and mineral fertilizers.

Crop system Long crop rotation, direct-seeding and cover crops



This cereal farm is located in the southwest of France (25 km south of Toulouse), in the agricultural region of Lauragais. Under the influence of the CAP, the local farms have progressively specialized in the production of durum and winter wheat as well as sunflower.

Photo: Solagro

Description of the farm

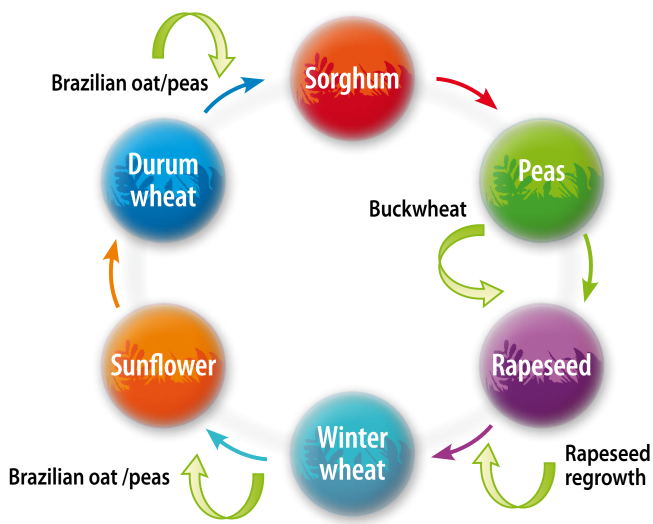
- 177 ha of rainfed cereals and protein-oil crops.
- 2 Annual Work Unit (2 brothers).
- Clay-limestone soils and non-calcareous clay and sandy soils, 50% of undrained waterlogged soils.
- 10 to 25% cultivated slopes, strong erosion sensitivity.
- Average annual rainfall of 638 mm, 200 days per year of wind (vent d'Autan).
- Peri-urban area: some plots near houses.

The two brothers soon realised the growing vulnerability of the initial cropping system, due to the low number of crops in the crop sequence: difficulties to ensure a good crops establishment (climatic uncertainties and sensitivity to soil erosion) and economic risks through price volatility. A complete change in the agricultural system has been implemented, including an increasing in the number of crops.

The main steps of change

The current cropping pattern of the farm

The resizing of plots of the farm in 6 areas of identical size has allowed the establishment of a balanced crop rotation composed of six main crops. Winter crops alternate with spring crops and cereals alternate with oilseeds and protein crops. Also, sown cover crops (oat, peas, buckwheat) or the crop regrowth (rapeseed) allow higher soil coverage than before.



The current established crop rotation sequence has been progressively modified to obtain a succession of crops consistent with the local soil and climate conditions, while meeting the farmer's agronomic and environmental objectives:

- Sorghum: rotation head of the cropping system, drought-resistant plant, strong root potential restructuring the soil.
- Peas: synthetic fixation of atmospheric nitrogen that enhances soil fertility, low root development and sensitivity to water excess compensated by the sorghum's soil tillage.
- Buckwheat cover: rapid growth, resistant to drought, quick degradation of residues, offers a melliferous potential towards pollinators.
- Rapeseed: good efficiency of the residual nitrogen left by the peas, after harvesting rapeseed, the regrowth can provide a plant cover function and food for potentially harmful slugs for the next crop.
- Winter wheat: sown directly in the rapeseed regrowth, wheat residues are left on the soil.
- Cover composed of peas and Brazilian oat: soil protection (long intercrop period of 9 months), atmospheric nitrogen fixation by peas, early destruction of the cover crop to meet the needs of soil temperature for sunflower.
- Durum wheat: sown in the sunflower residues, wheat residues left on the soil and sowing of a cover composed of peas and Brazilian oat before the sorghum.

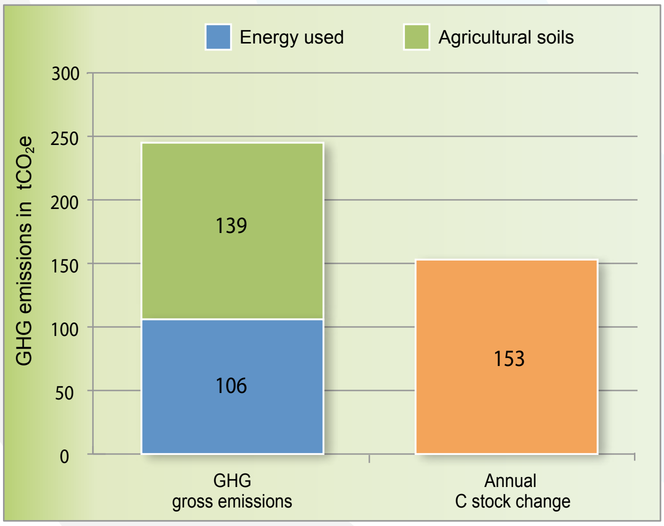
Energy and GHG emissions assessment of the farm

The farm holding is characterized by a very low level of energy consumption per ha of UAA, with only 9.7 GJ/ha, knowing that the average consumption is 14.5 GJ/ha for a group of 155 French rainfed crop farms[1] (-33%).

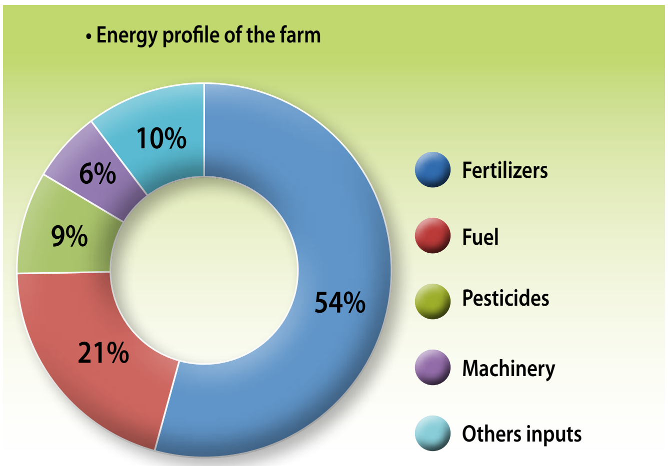
Also, the indicator of energy per tonne of dry matter (t dm) that indicates the energy efficiency for crop farms is 3.16 GJ/t dm, which is slightly below the average of the reference group[1] (3.21 GJ/t dm). Thus, the established agricultural system allows a very low energy consumption per ha and a good energy efficiency of the products.

The farm emits annually 245.15 tCO_2e, which corresponds to an annual GHG gross emission of 1.43 tCO_2e/ha of UAA. These results are 30% lower than the GHG emissions of the reference group with an average of 2.03 tCO_2e/ha UAA.

57% of the GHG gross emissions come from soils (mineral nitrogen applied, nitrogen in crop residues), the rest of the emissions (43%) come from energy used (processing of mineral fertilizers, fuel for tractors…). The main part of the GHG emissions (66%) is performed directly on the farm, while 34% are generated upstream of it. A set of favourable agricultural practices (no-tillage, cover crops, development of hedges) would allow the farm to increase its carbon stock to a compensation level of 61% of the total annual GHG gross emissions. Thus, the net GHG emissions would only be 0.56 tCO_2e/ha.



Total GHG emissions of the farm and annual carbon stock change (tCO_2e)



The benefits of the actions implemented

The actions implemented on the farm helped to reduce the energy consumption by **42%** and GHG emissions by **42%** while significantly increasing the annual carbon sequestered on the farm: **compensation of 61% of the GHG emissions**.

Direct-seeding extended to the entire surface of the farm resulted in a 65% decrease of the initial fuel consumption, compared to the period when ploughing was practiced. With currently 45 litres of fuel per ha of UAA, this input has been optimised to the maximum of the technical feasibility. At the farm level, direct-seeding is a decisive measure to reduce energy and GHG emissions as well as for additional carbon sequestration in soils. In 10 years,

[1] METAYER N., BOCHU J-L., BORDET A-C., TREVISIOL A. Références PLANETE 2010, Fiche 3- Production «Grandes cultures strict». Toulouse : SOLAGRO, 2010, 33 p. http://www.solagro.org/site/424.html

Measure	Energy reduction	GHG reduction	Contribution to the current annual C stock changes
Direct-seeding	24%	11%	74%
Cover crops	3%	5%	20%
Leguminous (16% of UAA)	9%	15%	0%
Nitrogen Balance	6%	12%	0%
Planting hedges	0%	0%	1%
Agroforestry (10 ha)	0%	0%	2%
TOTAL FARM	**42%**	**42%**	**97%**

the organic matter content has doubled in parallel to an increase of the biological soil activity and improved soil aeration.
Farmers have established annual small-scale field trials to test and select the cover crops (mixed species) that satisfy their objectives.
The choice of the type of cover crops is multifactorial: seed production and autonomy, complementarity of species, ease of germination, power of soil structuration, incorporation of biomass in the soil… The choice of cover crops is not fixed, it is the climatic conditions of the year that will guide the farmers' decisions.
Cover crops annually represent 52 ha at the farm level and ensure a soil protection against risks of erosion and nitrogen leakage during winter periods. The biomass produced by cover crops enhances the soil fertility, with

a recycling of nutrients around 20 kg of nitrogen per ha for the following crop, and reduces mineral nitrogen fertilizers purchased. Cover crops have a significant impact on increasing the carbon stock at farm level.

Previously, the cropping pattern did not include any legume crop. The introduction of peas has reduced the overall dependency of the farm for mineral fertilizers, as substituted crops received before 150 kg of mineral nitrogen per ha. Also, protein crops have the advantage of

Oilseed rape regrowth assuming the role of cover crop

leaving a recycle of nitrogen for the next crop (rapeseed on this farm), which reduces the mineral nitrogen purchased to around 30 kg N/ha. The share of 16% of protein crops in the total UAA impacts significantly on the reduction of GHG emissions at the farm level as well as its total energy consumption.
The fertilization plan based on an annual nitrogen balance at the farm level is necessary to quantify the total nitrogen surplus. This way, the farm has progressively decreased the nitrogen applied on the crops by seeking


Agroforestry in a plot of cereals *Photo: Solagro*

a balance with the needs of plants. For this reason, it is important not to overestimate the expected yield of the crops otherwise a high surplus of nitrogen could be observed. Progressively, the farm surplus of nitrogen decreased from 50 to 10 kg of N/ha. Its control can significantly reduce the indirect GHG emissions from soils. In 10 years, more than 2,000 linear metres of hedges have been planted to reduce the size of the plots while fighting against soil erosion. These ecological infrastructures are favourable to the development of auxiliary fauna; the prunings are used for the production of fragmented wood branches to improve the soil fertility.
At the beginning of the year 2013, a 10 ha plot has also been converted into agroforestry with 400 trees planted.

Other benefits noted

- Soils of the farm are restored with disappearance of erosion phenomena, better water infiltration in case of heavy rains, increase of the productive potential of these plots.
- Better weeds control, limited slug pressure on the main crop.
- Biodiversity enhanced through the planting of hedges.
- Reduction of working time and economic expenditures (reduction of inputs: fuel for tractors, mineral fertilizers…).
- Free time used to educate, communicate and convey a different image of agriculture by welcoming many people on the farm.

Recommendations from the farmers

Steps have to be respected in the dynamic of changes in the system. The priority is to restore a good biological soil activity by removing soil tillage and implementing cover crops knowing that it takes time. Once the soil activity has been reactivated, other changes can occur: include new crops, reduction of pesticides and mineral fertilizers…
The desire not to be alone with their difficulties and learn from other farmer experiences led to the creation of an association called AOC Sol[1] whose objective is to promote soil conservation.

Upcoming changes on the farm

- To double the share of protein crops in the cropping pattern, introduction of chickpeas that replace sunflower, poorly adapted to direct-seeding.
- To include species in cover crops that offer a possibility to be harvested (buckwheat, sunflower) which will increase productive potential of the farm.

[1] http://aocsols.free.fr/

Soil cultivation after winter flooding

Measure	Energy reduction	GHG reduction
Nitrogen fertilizer reduction	8%	6%
Shared machinery and works	4%	1%
Lower sowing density	2%	0%
Implementation of ecological infrastructures	2%	0%
Better water and straw management	0%	23%
TOTAL FARM	**15%**	**31%**

Rice emissions worldwide are known to be linked to water management and flooding practices (CH_4 emissions) and also to nitrogen fertilization (N_2O emissions). This is due to a complex relationship between the methanogenesis process under anoxic conditions, the activity of nitrifying and denitrifying bacteria, the nitrogen added to the system and the agronomic practices. To be successful in the implementation of mitigation measures on rice, at least these major problems have to be faced.

Nevertheless, the successful implementation of these measures relies on farmers' acceptance, and in most cases this is linked to money and time savings and to expected similar yields. For example, a reduction in the nitrogen fertilizers is a very interesting option to reduce GHG emissions when the nitrogen surplus in the farms is excessive, but in the Albufera area the cost reduction for farmers was not significant (20-30 €/ha) and thus it was not implemented, even if it was demonstrated in several meetings that some of the farmers that had over fertilized had smaller yields. In the Albufera case study, 4 farms out of 8 were affected by a surplus of nitrogen between 30 and 78 kg of N/ha, which represents between 17 and 37% of the total amount of nitrogen inputs. As it is frequently observed in crop systems, over nitrogen fertilization is traditionally linked to the idea of securing the crop yield, and this can be a significant constraint to address.

Measures directly linked to energy saving but with a lower impact on GHG emissions, such as shared machinery and lower density sowing, have a wider acceptance by farmers. In the case study area, a direct saving of 10 litres/ha of fuel (with added benefits such as machinery maintenance cost reduction and time saved on the farm) and a 34-50 €/ha saving on seed purchase (with added benefits such as an expected reduction in fungicides treatments) was confirmed. The implementation of ecological infrastructures was also welcome by some farmers in the Albufera area, as previous local studies (done by Fundació Assut in cooperation with the Universitat Politécnica de Valencia) have demonstrated that field edges planted with autochthonous vegetation (in this case, *Spartina versicolor*) are an important refuge for rice pest enemies, and thus can be helpful to reduce energy and GHG emissions related to pesticides. But again, the main interest for farmers was that these natural vegetated edges are less time and money consuming, compared to artificial edges that have to be restored and sprayed with herbicides on the ground every year and represent a significant fuel consumption and time consuming work.

Ecological infrastructure (Spartina versicolor) in the Albufera area

Water and straw management is, as demonstrated worldwide, the most effective measure for GHG reduction. Methane emissions depend on the cultivation period in days, water regime before and during cultivation, and the straw and organic matter management. Changes in the water management practices, whenever possible, are generally accepted by farmers as it does not involve investments, additional costs or significant changes in the crop management. Nevertheless in the Albufera case study area these practices were found to be very complex to implement. The main constraint is that the historical irrigation system partially reduces the possibility of controlling water regimes and cultivation periods, as more than 20,000 ha are managed together concerning water, so the reduction of GHG emissions are limited to the straw management. The traditional practice among farmers was to burn the rice straw, now deterred by the CAP and local regulations. Several attempts to use harvested straw have been put in place such as bedding for animals. But the value of rice straw is not so high locally, the harvesting cost is increasing and the harvest can only be considered as one of the possible options. Straw chopping is another option but it also increases the harvesting cost and investment.

Traditional practice of rice straw burning

Finally, suitable management of water after harvesting was found to be one of the most effective measures: to wash the straw and/or to not flood at least for some weeks to avoid fresh organic matter flooding. But sometimes this management has an additional pumping cost, is not possible due to the rainy conditions, or other priorities are envisaged by farmers such as immediate flooding for hunting. So finally the implementation of these practices relies essentially on individual farmer's commitment.

GPS Technologies for precision agriculture

Location:
Perugia, Umbria region, (middle Italy)

Photo: Pietro Peccia - Az. Agricola Peccia

Description of the farm

- 110 ha UAA, mainly arable crops: durum and winter wheat, maize, barley, sunflower.
- Contractor for seeding to other farms.
- Annual production: 407 tonnes of wheat, 38 tonnes of maize, 17,5 tonnes of sunflower.

This farm is situated in the countryside on the outskirts of the municipality of Perugia, at 250 meters of altitude, and the microclimate is influenced by the nearby Lake Trasimeno.

The high costs for the fuel, due to the 110 ha of own fields and more than 400 ha worked for other farms, pushed the family to renew their existing fleets with more efficient agricultural machinery.

They bought a brand new tractor with a GPS driving system: a GPS receiver installed on the tractor connected to a display screen for assisted driving, and coupled to the system of sowing and fertilizing.

The application of this technology has permitted the farmers to obtain significant repayment immediately, with relatively low investment. The cost to equip a tractor (almost every tractor because it is a very adaptable system) with a GPS system is about 8,000 €: considering that during the 2011/2012 season they saved around 5% of fuel, around 10% of mineral fertilizers, around 5% of seeds and around 5% of working hours, the immediate cost savings were about more than 2,500 € for the owned fields.

With GPS technology, farmers can accurately guide their vehicles and have the benefit of less operator work and fuel and also significant savings for all the different operations of the field: planting, fertilizing, spraying of pesticides, cropping, harvesting and so on.

A significant added value is that farmers can record and collect geo-referenced data that can be used for field analyses: they can analyze crop performance and investigate variations within their field that contributed to a higher or lower crop yield such as differences in soil types, seed variety, nutrient availability, water run-off or pooling, and other important factors.

They can then adjust their farming practices for the next year to maximize productivity and profitability while reducing environmental impacts of the farm.

Case study
Dairy systems

The stakes are usually multiple (fuel, feedstuffs purchased, electricity, fertilizers) which implies the implementation of agronomic measures, livestock measures, carbon storage or energy saving and renewable energy production. The diversity of improvement actions is illustrated here through three examples:

- In Germany, a farm specialized in dairy milk and also including a biogas plant.
- Then, a farm producing sheep milk located in the south of France, having developed its production system with the installation of a solar dryer for fodder.
- Finally, in the presence of specific activities such as cheese manufacturing, the dependence on direct energies may become more sensitive. Alternatives around the renewable production of hot water are possible and developed on this farm in mountainous area (France).

Dairy farm with biogas plant

Location:
District of Constance
(Federal State of Baden-Württemberg)

Photo: Bodensee-Stiftung

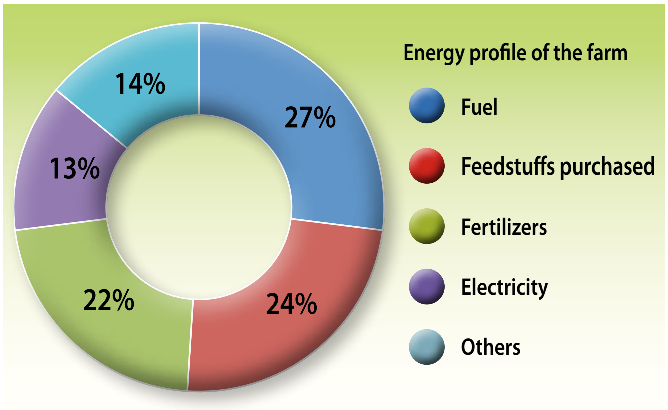
The Renewable Energy Law in Germany has stimulated the production of electric power in biogas plants in the last years. A special financial bonus for the use of manure makes biogas plants attractive for dairy farms. Most of the existing biogas plants are using manure as well as energetic crops, specially grown for the biogas plants. The first biogas plant in District of Constance started power production in 1997. Nowadays about 30 biogas plants are connected with the public energy grid in the district.

Description of the farm

- Average annual rainfall: 650 mm (Elevation: 650 m).
- 86.1 ha of UAA
  - 44 ha are permanent grasslands
  - 8 ha of perennial ryegrass
  - 30 ha of maize silage (including 9 ha after rye)
  - 9 ha of rye and 8 ha of sold wheat.
- Dairy milk
  - 51 dairy cows with offspring,
  - Annual milk production of 370 tonne
  - Around 7,250 litres of milk/cow/year.
- Biogas plant since 2003 with 150 kW electric output, fed with manure as well as energetic crops (maize silage, grass silage, rye silage).
- Conventional farming.

Energy and GHG emissions of the farm

The energy consumption of the farm consists of fuel (27%), feedstuff purchased (24%), fertilizers (22%), electricity (13%) and other inputs corresponding to farm buildings, machinery and farm plastics (14%). Thus, these 4 main sources represent 86% of the overall energy consumption.



Use of each energy source

Fuel is consumed by 40% for the dairy milk and another 40% for the crops for the biogas plant, while the remaining 20% are shared for cereals and employees' transportation. About 55% of the energy from bought feedstuff is used for the biogas plant (energetic crops) and 45% for dairy production. Fertilizers is linked mainly to dairy milk (65%), another 25% to biogas and 10% to cereals. Also, 80% of the consumed electricity from the grid is needed in the dairy production. The remaining 20% is mainly used in a small seasonal restaurant (open only for 4 months in summer) that cooks mainly products from the farm.

Energy consumption for each production

The energy input in 2011 was 3,338 GJ, which equals 38.8 GJ per hectare. The energy consumption of the different branches on the farm can be described as follows:

- Milk production uses approximately 50% of the overall energy consumption, mainly through fuel, electricity, fertilizer and bought feedstuffs.
- The biogas plant uses around **37%** of the overall energy consumption, mainly of fuel, bought energetic crops and fertilizer. Taking into account the energy produced by the biogas plant (electricity and heat), the installation is quite effective with 2.8 times more energy produced than consumed.
- The remaining **13%** of the overall energy consumption are related to the cereals, the seasonal restaurant and employees' transportation.

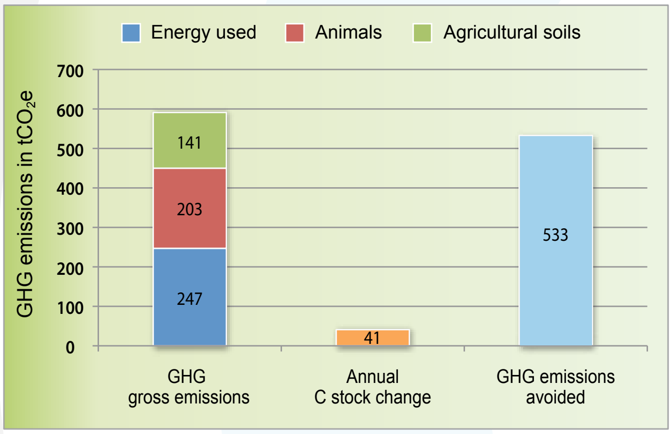
The farm emits annually about 591 tCO_2e, which equals to 6.86 tCO_2e per hectare of UAA. About half of the emissions (42%) originate in the used direct energy, 34% are linked to animal production, and 24% are emissions from the agricultural soils.

Due to intermediary crops, conservation of permanent grassland and hedges that function as carbon storage, a total of 41 tCO_2e can be stored annually. That represents 7% of the farms annual emissions.

The biogas plant is producing about 900 MWh of electricity per year. This electric power replaces the German electricity mix (coal, nuclear power, gas and renewable energy), which leads to significant CO_2 emissions avoided of about 485 tCO_2e. By using parts of the wasted heat that results of the electric power production, another 45 tCO_2e can be saved. This heat is used to heat the farmer's house, the restaurant as well as for the hot water production for the milking parlour. Thus, the GHG emissions avoided by the use of renewable energies in substitution to fossil fuels are comparable to the gross GHG emissions of the farm.

The main steps of change

In the course of the last three years, several types of measures have been implemented on the farm, dealing with investments or best agricultural practices. Most of these measures are related with the issues of the farm



• **Annual GHG gross emissions, carbon stock change and GHG emissions avoided by the production of renewable energies (in replacement of fossil energies) on the farm in tCO_2e**

(electricity, fuel, feedstuffs purchased and mineral fertilizers) and have so far proved to be quite efficient. A significant measure was the construction in 2012 of an additional fermenter for the biogas plant. This central and complex measure leads to significant changes on the farm. The fermentation time can be prolonged and thus the efficiency of the methane production can be increased. More methane leads to more electric power with the same amount of substrate. The higher capacity also enables the farmer to be more flexible in applying the digestate as manure, to be again more efficient while reducing emissions due to fertilization. Further applied mitigation measures consist of the reduction of concentrated feedstuff and the adjustment of the nitrogen balance of the farm.

Benefits of applied and planned measures

The described measures decrease energy consumption, or respectively allow a credit for the use of renewable energy about **45%** and decrease greenhouse gas emissions by about **30%**.

The biogas plant of the farm has existed since 2003. The plant is fed with liquid manure from dairy cattle and energetic crops (own production and purchased). The installation is useful to decrease GHG emissions from manure management, mainly methane (-54 tCO_2e). At the end of the year 2010 two little block heat and power plants (63 kW and 35 kW) were replaced by a bigger one (150 kW). This resulted in a 10% higher use of power (mainly because of the purchased fodder), but at the same time increases energy output (power) about 30%.

In 2012, the existing biogas plant was extended with an additional fermenter that allows the increase of methane as well as the produced power. An optimized use of the waste heat during the process can replace heating fuels, evaluated on this farm at about 40,000 litres. An external development must be found as all the farm's heating

Measure	Energy reduction	GHG reduction
Biogas plant	0%	8%
Planned action: additional use of waste heat from biogas	40%	15%
Reduction of electricity consumption	1%	0%
Renewal of old tractors	0%	0%
Adjust nitrogen balance	2%	2%
Less energetic feedstuffs in addititon to pasture	1%	4%
TOTAL FARM	**45%**	**30%**

needs are already covered by the waste heat: heating the workers apartment and also energy for the industrial production of ice. This measure leads to a theoretic energy yield of 1,407 GJ and a reduction of greenhouse gases by about 107 tCO_2e. The farmer would like to implement this measure, but a complex planning is necessary.
On the farm several measures to reduce energy consumption were implemented successively: new efficient heat pumps for instance were installed in the heating system to save on electric energy, the dunging of the livestock building was adjusted at lower interval in consideration of animal health and the temperature management in the milk storage room has been optimised through a simple roof hatch to release the warm air, which reduces the operation time of the milk tank. These measures decreased the annual electricity consumption by 10% (4,000 kWh), respectively 41.6 GJ and 2.1 tCO_2e.


Photo: solarcomplex AG

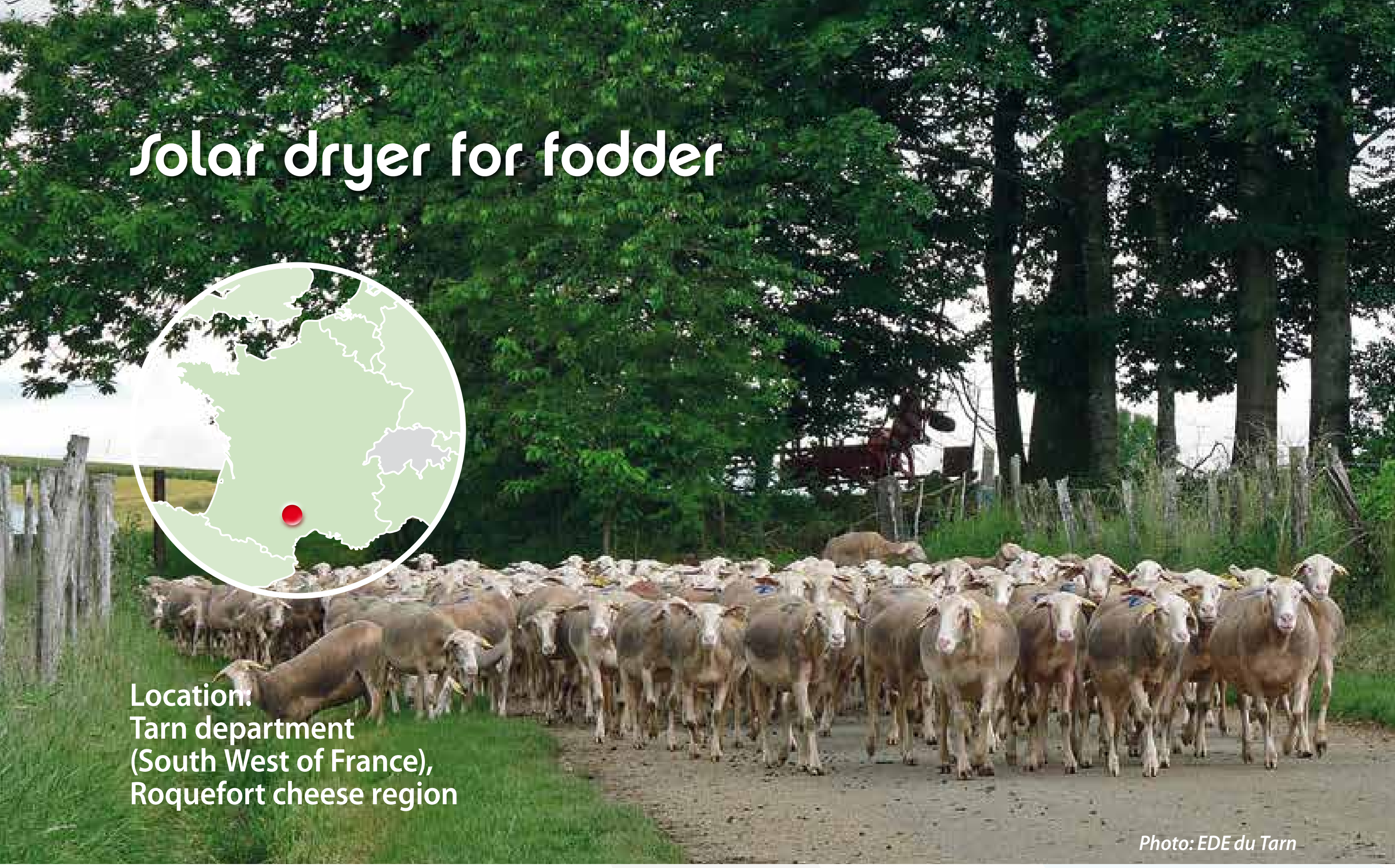
Engine used into the biogas plant

The replacement of two old machines (a 21-year old tractor and a 40-year old wheel loader) by two new machines reduces fuel (reduction of 12 GJ and of 3 tCO_2e).
The use of legumes as green manure replaces a part (8%) of the mineral fertilizer purchased. Thus, the reduction of 1 tonne of mineral nitrogen fertilizer, is accompanied by an energy reduction of 55 GJ and a GHG reduction of 17 tCO_2e.
A potential reduction in the dairy sector is to decrease the energy input in the fodder production. About 72 tonnes of concentrated feedstuff with crude protein content of 40% could theoretically be replaced by the same amount of concentrated feedstuff with 20% crude protein and additional pasture. This allows an energy reduction of 41 GJ, respectively 12% and a reduction of GHG emissions of 28 tCO_2e, respectively 28%.

Other benefits

In addition to maintaining permanent grasslands (50% of the UAA), the farmers cultivate 43 ha of arable land without ploughing. Besides, the family is engaged in public relations and supports the project *AgriClimateChange* in many different ways.

Solar dryer for fodder



Location:
Tarn department (South West of France), Roquefort cheese region

Description of the farm

- 42 ha UAA, only fodder surfaces.
- 300 ewes (Lacaune breed) and 80 ewes lamb.
- Annual production of 67,200 litres of milk and 276 lambs.
- Energy profile of the farm: feedstuffs purchased (44%), fuel (17%), electricity (16%).
- Main sources of GHG emissions: enteric fermentation and manure storage (73%), direct soil emissions (10%), feedstuffs purchased (9%).

Faced with regular drought problems limiting the farm autonomy in fodder and the milk production, the farmers have decided to build a solar dryer for fodder in order to improve its quality (nitrogen content) while reducing the dependence of the farm on external concentrates. The solar dryer system is based on the recovery of hot air under the roof (presence of an insulating material) that allows recovering the calories accumulated during sunny periods. The particularity of this roof is to provide, in addition to the function as solar sensor, electricity production thanks to 1,300 m^2 of photovoltaic panels.

The hot air recovered under the roof is then pulsed by a fan through two cells (total capacity of 150 tonnes) where the loose hay is stored. A hydraulic forage claw on rails allows the handling of forage to the hay barn at harvest and then it is distributed to the animals during the winter. This solar dryer system secures the quality of the harvested fodder, particularly by reducing half of the drying rate compared to the use of ambient air.

The feedstuff purchased, which represented 44% of the total energy consumption of the farm, has been halved, once the fodder from the solar dryer was consumed. Also, external purchases of fodder were stopped and the fuel consumption for tractors has decreased by around 30%. In addition to these benefits, the fodder is more appetising which resulted in a 15% increase of the milk production of the farm. However, the consumption of electricity from the grid has increased (from 10,000 kWh/year to 25,000 kWh/year) for the operation of both fan and claw, but this is largely compensated by the annual production of 200,000 kWh of renewable electricity by the photovoltaic panels. Finally, the farm realises an energy saving of about **46%** and of its GHG emissions by **6%**.

Forage claw on rails for hay handling

Solar panels for heating water in a cheese factory

Location:
Aveyron department (South West of France), Laguiole cheese region

Aubrac cows in the region of Laguiole

Photo: Solagro

Description of the farm:

- 2011's, organic certification.
- 55 ha UAA, only permanent grasslands.
- 27 cows (Simmental breed).
- Annual production of 120,000 litres of milk.
- Energy profile of the farm: electricity (47%), feedstuffs purchased (20%), fuel (18%).
- Main sources of GHG emissions: enteric fermentation and manure storage (71%), direct soils emissions (9%), feedstuffs purchased (8%).

This dairy farm is situated on the plateau of Aubrac at an altitude of 1,000 meters, and belongs to the production area of the AOC (registered designation of origin) Laguiole cheese, which gathers 80 producers. The establishment of the son into farming on the family farm was the source of a project to create a cheese factory equipped with a maturing room, to transform progressively the entire milk production. The energetic assessment performed before the cheese factory project had already showed the heavy weight of electricity grid consumption, which accounts for **47%** of the total energy consumption of the farm. The main consumption sources are the operation for the milking system (production of hot water, milk tank and vacuum pump).

Cheese processing will double the hot water needs of the farm, rising from 200 to 400 litres per day. To cope with these new expenditures, the farmers have decided to invest in solar thermal panels to ensure **50% to 60%** savings on the electricity bill. Milk processing will take place throughout the year with a peak of milk production in late spring, also corresponding to a significant solar coverage rate. The payback period of investment will be about 10 years for this farm, taking into account that it has benefited from a grant[1] of 50% of the total cost.

[1] The Energy Performance Plan (PPE) of the French Ministry of Agriculture and Fisheries aims to improve the overall energy efficiency of the farms.
More information: http://agriculture.gouv.fr/plan-performance-energetique-des

Case studies
Arboriculture and viticulture systems

The proposed improvement actions are usually related to agronomic levers for these farming systems. However, when particular activities are in place on the farm (storage, wine...), specific and complementary measures can be developed. Three contrasted examples in terms of size, agricultural production and climate illustrated these improvement actions:

- First in Spain, in an area for citriculture production on small farms, some agronomic opportunities (fertilization, irrigation, cover crops) adapted to different farming systems were tested.
- In Germany, a farm producing and storing fruit in a cold room recovers energy as heat after cooling.
- Finally in Italy, the valorisation of roofs on a winery farm to install photovoltaic panels can strengthen the electricity autonomy of the winery.

Citriculture in the region of Valencia

Location:
Eastern Spain
(Valencia and Castellon)

Photo: Jordi Domingo-FGN

20 orange farms located in the east of Spain (Valencia and Castellón), in an agricultural landscape mainly dominated by orange farms were assessed. Under the influence of regional plans, some of the traditional farms irrigated by gravity have been transformed into a drip irrigation system, usually depending on a central pumping station that can irrigate very large surfaces. Orange crops need high inputs of nitrogen fertilizers and in the last few years the benefits for farmers have been severely reduced due to the increasing prices and dependency on inputs.

Description of the farms

- 20 farms with different varieties of oranges and tangerines.
- Average size: 0.8 ha UAA per farm.
- 12 farms with surface irrigation by gravity and 8 farms drip irrigated.
- Average yield: 22.5 tonnes per ha.
- Average mineral fertilizers on conventional farms: 213 kg N/ha.

Oranges, tangerines and other Citrus species have been cultivated in subtropical areas of Southeast Asia and other parts of the world since ancient times, but were traditionally used for ornamental and medicinal purposes. The modern citriculture, that is the production of oranges and tangerines for food purposes, began in the Valencia region at the end of the 18th century. One century later, and especially during the first half of the 20th century, the whole agricultural landscape was transformed with more than 180,000 ha nowadays (35% of the agricultural soils), accompanied by an economical revolution. The orange trade currently represents a 622 million € business, which is 16% of the total exports from the Valencia region.

Photo: Jordi Domingo-FGN

The main changes and current situation

Traditional oranges farms changed dramatically in the 1950s. Until then, the high nitrogen needs were met using local manures, no herbicides were sprayed and cover crops contributed to the conservation of soils. Pesticides were unknown and the use of machinery was not extended. Orange farms benefited from the traditional irrigation infrastructures developed between the 13th and 19th century, using water from rivers that was distributed by gravity to large cropland areas. Consequently, the energy used in the farms and agricultural inputs were reduced to a minimum. International exports and low cost farming inputs contributed to a well-established and powerful farming society. Until then, farmers could make their living by farming a surface of 1.5 ha.

From the 1960s onwards, important changes were implemented to increase the yields and thus farmers' benefits that were directly related to the production. The "Green Revolution" introduced mineral fertilizers, herbicides, pesticides, new and more productive varieties but more dependent on inputs, and machinery that eased farmers' work... but all theses changes also created a high dependence on external inputs. During the last decade of the 20th century, another important change was promoted by regional institutions and farmer communities in order to reduce water consumption, ease farmers' work and increase the fertilizing effectiveness: a significant part of the traditional irrigated farms was substituted by drip irrigation systems, where water is pumped through electricity to a vast surface of farms using pipes. Fertilization and irrigation periods are controlled by the irrigation community (landowners in the irrigated area) and farmers bear the cost of the pumping and fertilization service, as well as the local equipment needed at the farm. This continuous modernisation process has certainly improved farmers' benefits and has eased their way of life, but on the other hand has lead to a difficult situation where the high dependence on external inputs and the continuous decreased fruit prices is nowadays hindering the survival of a lot of farms.

Energy and GHG emissions assessment of the farm

To have a good overview of the citriculture sector concerning energy and GHG aspects, 20 farms were selected representing the current situation, thus including surface and drip irrigation, whether in conventional agriculture (13 farms) or organic farming (7 farms).

Concerning the irrigation system, surface irrigated farms (12 farms) in average have proved to be more efficient in the use of energy, both per surface (22.4 GJ/ha) and for production (0.95 GJ/tonne) than drip irrigation systems (29.98 GJ/ha and 1.35 GJ/tonne), although significant variations are noted between farms (Figure 1).

In surface irrigation farms (8 farms), fertilizers (52%) and fuel consumption (32%) represent the main energy consumption for the farms, with minor consumptions concerning machinery (9%) and others such as pesticides (5%), plastic bags, etc. (2%).

In drip irrigated farms, 55% of the energy consumed is

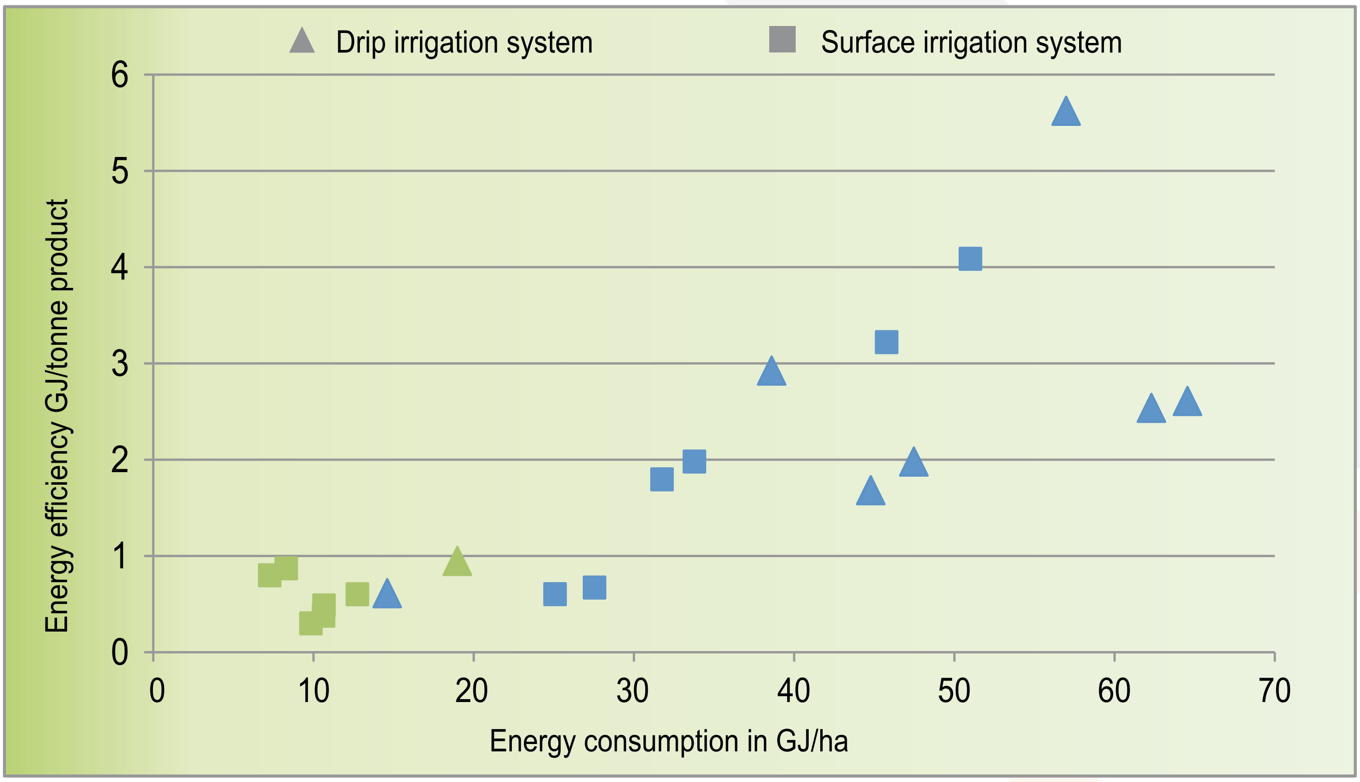


Figure 1: Energy consumption per ha and per tonne of product for drip and surface irrigation system. Blue colour corresponds to conventional farms and green colour to organic farms

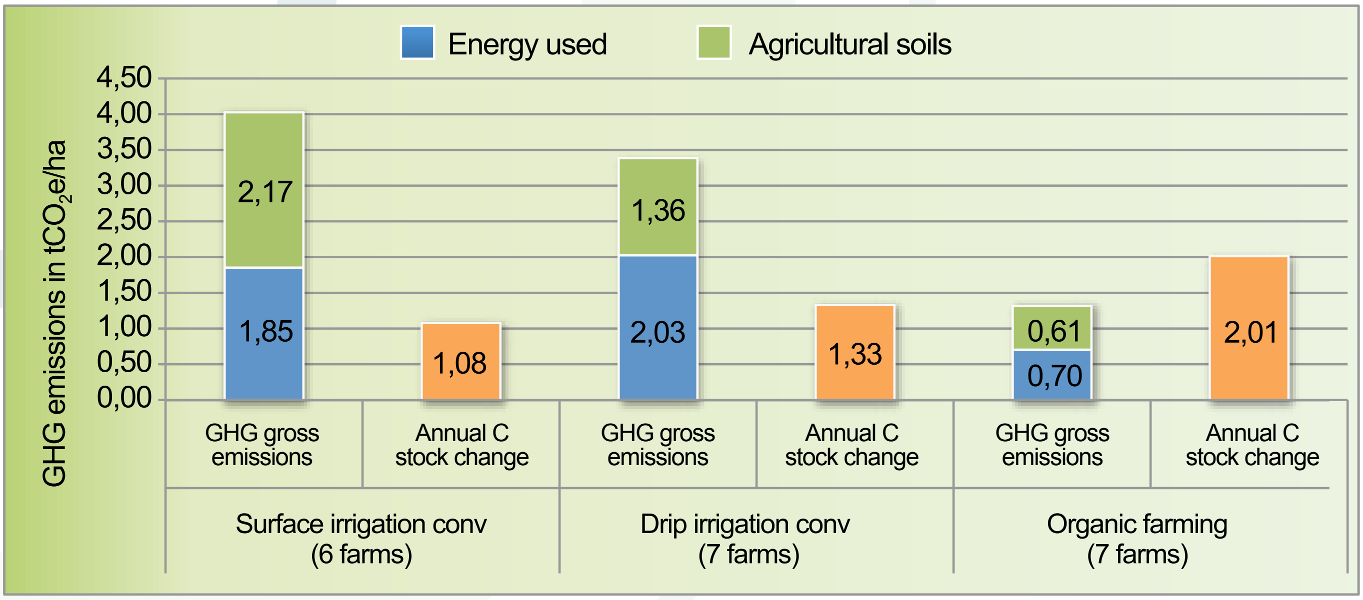


Figure 2: Annual GHG emissions and C stock change for conventional farms under surface irrigation, conventional farms under drip irrigation system and organic farms

related to the pumping irrigation system and fertilizers represent a 14%. Nevertheless, as fertilizing is managed for the whole irrigation community through the drip system, this energy cost is not directly controlled by the farmers who cannot change the fertilizing dose on their own. This means that at least a 70% energy cost in this system does not depend on the farmers' individual decision. The rest of the energy costs related to the farm are fuel consumption (19%), plastics and irrigation equipments 7%, machinery 4% and pesticides (1%).
Concerning the comparison between organic and conventional farms, organic farms are clearly more efficient in the use of energy, both per surface and production. The results on Figure 1 show that organic farms have a lower energy consumption, both per ha and per tonne. This is mainly explained by the replacement of mineral fertilizers with local manure. In some cases, even a decrease in the fertilizers applied has been realised by organic farmers that have implemented cover crops for long periods. Herbicides are not used and insecticide treatments are reduced to a mineral oil spraying in summer. Fuel consumption (87%), plastic bags (8%) and fertilizers (5%) are the most important energy consumptions on these farms. Only in one of the organic farms assessed, electric power was used for irrigation and then represents 59% of the total energy consumption of this farm.

GHG emissions related to energy consumption are quite similar for both irrigating systems (1.85 tCO_2e/ha for surface and 2.03 tCO_2e/ha for drip) with higher differences on emissions related to agricultural soils (2.17 tCO_2e/ha for surface and 1.36 tCO_2e/ha for drip). But again very significant differences exist between organic and conventional farms, with an average total of GHG gross emissions of 1.31 tCO_2e/ha for organic farms and 3.7 tCO_2e/ha for conventional farms. Similar observations concern carbon sequestration, with an additional carbon storage per ha twice as high in organic farms compared to conventional farms explained by the systematic implementation of cover crop.

The benefits of the implemented actions

Due to the existence of differences in management systems, mitigation measures were differentiated for orange farms. For drip irrigation systems, for which energy for fertigation could not be controlled directly by farmers, the establishment of irrigation sensors was the only feasible and effective measure with an average decrease of **29%** of the overall energy consumption and a decrease of **14%** of the GHG emissions.
For surface irrigation farms, action plans are focused on nitrogen fertilizer reduction, implementation of cover crops (thus reducing to a minimum the use of herbicides and fuel consumption), and implementation of ecological infrastructures. For conventional farms, the overall energy consumption has decreased by **19%** and the GHG emissions have decreased by **20%** while an additional carbon sequestration is observed. For organic farms, the gains are lower with an average reduction of energy of **9%** and **6%** for GHG emissions, which is explained by their current lower levels of energy consumption and GHG emissions compared to conventional farms.
Nitrogen balance was poorly implemented as most of the farmers want to secure their yield, even if it was demonstrated that higher nitrogen inputs are not necessarily related to a higher yield and can sometimes cause additional problems with pests or weeds. Most of the farms could reduce their nitrogen fertilization by

Measure	DRIP IRRIGATION conv		SURFACE IRRIGATION conv			ORGANIC FARMING		
	Energy reduction	GHG reduction	Energy reduction	GHG reduction	Contribution to the current annual C stock changes	Energy reduction	GHG reduction	Contribution to the current annual C stock changes
Nitrogen balance	–	–	10%	11%	0%	1%	4%	0%
Cover crops	–	–	9%	9%	40%	8%	2%	10%
Irrigation sensors	29%	14%	not concerned	not concerned	not concerned	not concerned	not concerned	not concerned
TOTAL FARM	29%	14%	19%	20%	40%	9%	6%	10%

between 5% and 15%. Moreover, the price of nitrogen fertilizers is still too low compared to the expected savings from fertilizers for such small plots (0.8 ha UAA), that it is not insensitive enough for farmers.

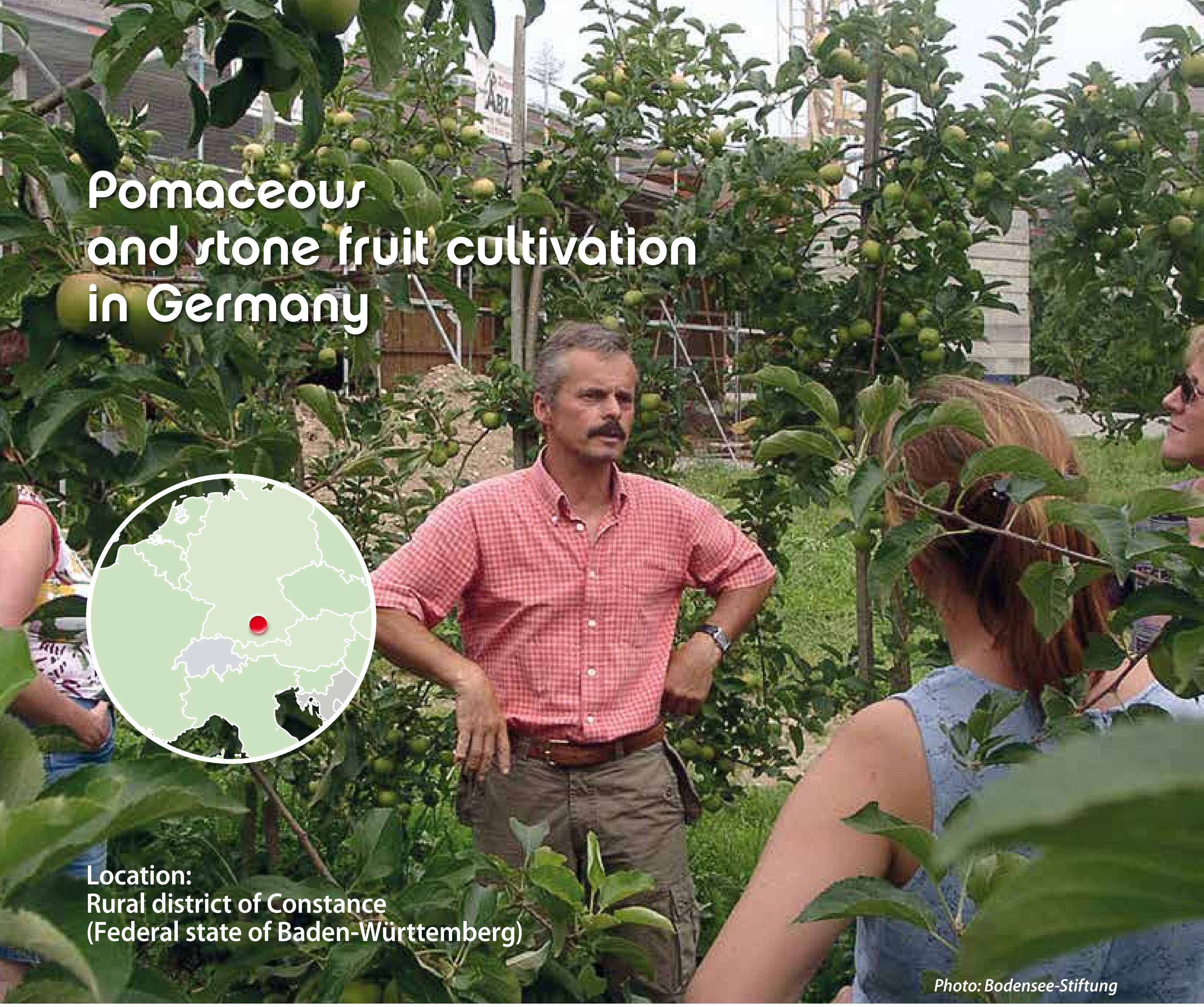
On the other hand, the introduction of cover crop is a successful measure mainly because it has transversal benefits, such as reducing or eliminating herbicides treatments and tillage, with a direct impact on direct energy saving, thus in money saving. Uncovered soils sprayed with herbicides represent a relatively new agricultural practice. Most of the farmers still remember that they could manage their farms without using herbicides, which makes it easier to convince them to go back to this former management.

The implementation of ecological infrastructures through the plantation of young hedges is not for now a significant increase in the carbon storage at the farm level. Nevertheless this measure will show its benefits as carbon sink in the medium term.

Finally the irrigation sensor measure implemented on drip irrigation farms is very efficient concerning energy and GHG reduction, in addition to a good value for money with a return of the investment (due to electricity saving) in a few years. Irrigation sensors are connected to a central computer that controls water needs and conductivity. Another benefit untested would be to improve the nitrogen management by reducing nitrogen leaching.

Cover crops under orange trees

Pomaceous and stone fruit cultivation in Germany



Location:
Rural district of Constance
(Federal state of Baden-Württemberg)

Photo: Bodensee-Stiftung

Description of the farm

- 18.4 ha UAA, full-time farm with pomaceous and stone fruit cultivation (15.2 ha apples, 2.9 ha red + black currants, 0.3 ha plumes).
- Annual fruit production: 555 tonnes.
- Own Controlled Atmosphere (CA)-cold storage rooms for apples.
- Energy profile of the farm: electricity 60%, fuel 16%, plastics and packaging 8%, farm buildings 6%.
- Main GHG emissions sources: electricity 34%, fuel, 23%, farm buildings 10%.

Use of waste heat from cold storage rooms

60% of the farm's overall energy consumption results from the demand for electricity by the CA-cold storage. Therefore it's worth developping measures to use electricity more efficiently.

Thanks to the special CA cooling technology, local apples can be stored fresh from harvest in autumn until late spring without any loss of quality. Besides a high air humidity, a high CO_2 and a low oxygen content in the cold storage room a constantly low temperature of 2-3°C is necessary. The farm needs a lot of electricity for this

Applied measures

Measure	Energy reduction	GHG reduction
Use of waste heat from cold storage rooms	26%	15%
Combined driving	1%	2%
New fuel-efficient tractor	3%	5%
TOTAL FARM	**30%**	**21%**

cooling process that covers several months, especially because the cold storage rooms are so large that the harvests of neighbouring farms can also be stored. The farm's electricity consumption over the last three years was about 70,000 kWh per year. The waste heat from the cooling system had to be expulsed out of the storage building with ventilators.
To use the waste heat, the farmer has installed heat exchangers to absorb the heat from the outgoing air. The therewith-preheated water is used for the hot water generation with a supplement provided by woodchip heating. Finally the hot water is used for heating two apartment houses. Also some accommodations for seasonal workers are planned. Then the big amount of heat in autumn, during the start of apple storage, can be used too (heating and hot water showers). The complete construction was put on stream in March 2013. The capital cost was about 65,000 € (planning, heat exchangers, hot water buffer storage, woodchip heating, local heat pipes). The estimated annual energy benefit is 30,000 kWh, which represents 7.05 tCO_2e of GHG emissions avoided by the non-use of electricity from the grid.

This measure will help the farm holding to decrease the total energy consumption by **26%** and the total GHG emissions by **15%**.

Combined driving: Mulch machine and pesticide sprayer

Diesel is the second big energy consumption of the farm (16%). The frequent driving with the tractor in the fruit orchards, causes an annual consumption of about 200 litres of diesel per hectare.
The combination of two work processes (mulching and spraying) can reduce the number of rides in a range of 5 to 7 rides per year. The combined driving uses about 20% more fuel per ride, but as the number of rides per ha is reduced, that allows at the end a reduction of fuel at the farm level. The farmer will test this technique on 12 ha during the time of June and September 2013 with his new tractor.
The expected reduction of fuel is around 290 litres of diesel per year, which represents 7% of the current fuel consumption of the farm. The price of the technique is in the range of 20,000 €.

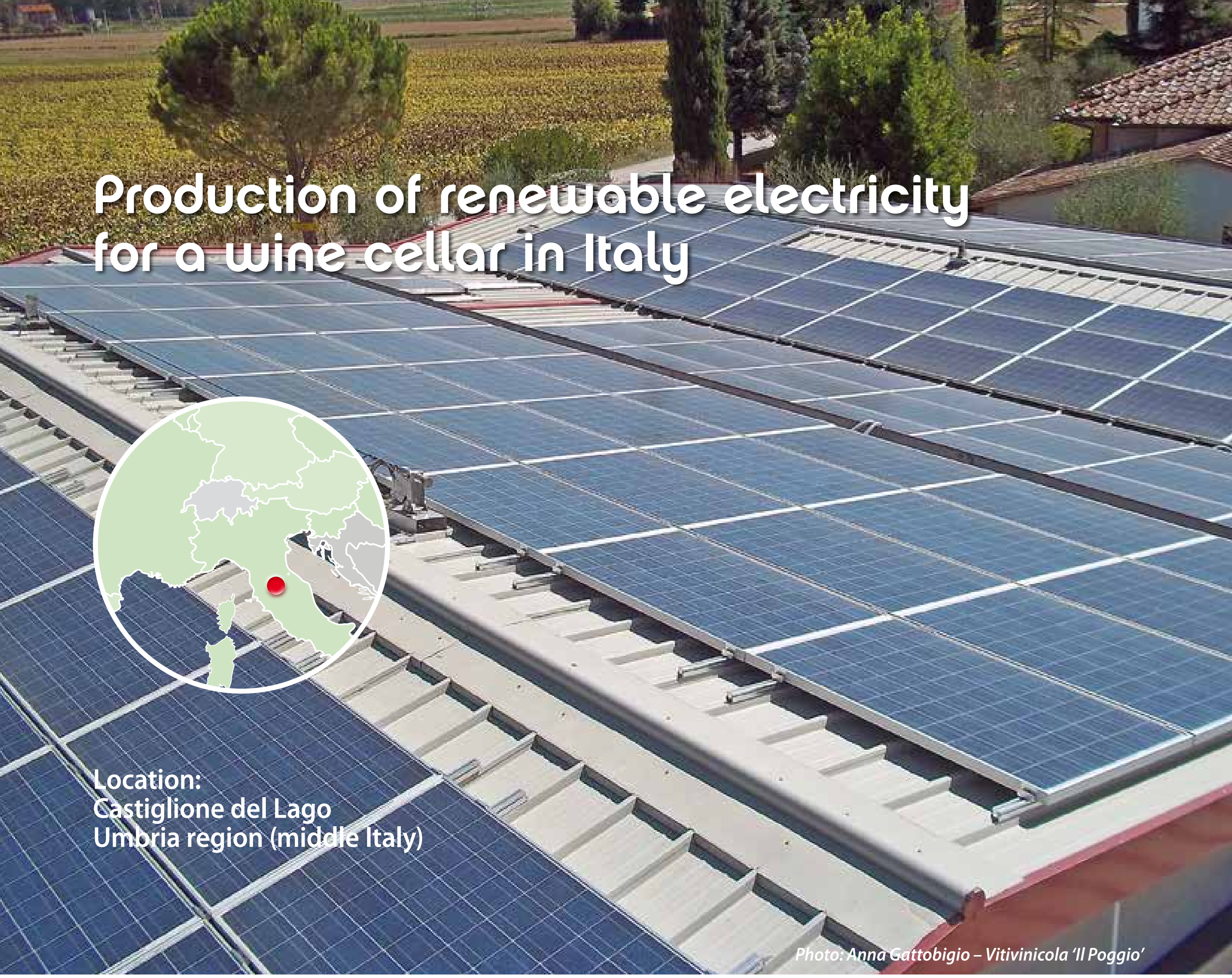
Photo: Jochen Griebel (WOG Öhringen)

Acquisition of a new fuel-efficient tractor

The previous tractor was about 30 years old. The reduction potential of diesel due to a new fuel-efficient tractor is in the range of 800 litres of diesel per year, or 20% of the farmer´s total fuel consumption. The new tractor was bought in 2012 for the sum of around 60,000 €.

At the end, these two measures (combined driving and the renewal of a tractor) explain a decrease of 27% of the total fuel consumption, which corresponds to a decrease of **4%** of the total energy consumption of the farm and a decrease of **7%** of the total GHG emissions of the farm.

Production of renewable electricity for a wine cellar in Italy



Location:
Castiglione del Lago
Umbria region (middle Italy)

Photo: Anna Gattobigio – Vitivinicola 'Il Poggio'

Description of the farm

- 8 ha UAA of vineyard, different types of grape variety.
- Annual production: 50 tonnes of grape, 300 hectolitres of wine.
- Energy profile of the farm: packaging/bottles 43%, electricity 23%, fuel 20%.
- Main GHG emission sources of the farm: packaging/bottles 53%, fuel 17%, electricity from the grid 13%.
- Annual electricity consumption (before the implementation of the photovoltaic panels): 12,500 kWh/year.

This small wine farm is located in the gentle hills of the south side of Trasimeno Lake, at 260 meters of altitude. Thanks to the quality of the grapes, the farm is part of the "Trasimeno Hills Wine Road", non-profit association committed to the development of the local area.

In 2005, the farmers decided to renew the winery with new barrels in order to obtain high quality wine. To preserve the taste and the typical flavour of each grape, every barrel is dedicated to specific qualities of wine.

Later was also implemented a cooling system for fermentation, with increased costs for electricity consumption. Thus, electricity represented 23% of the total energy consumption of the farm. This is the reason, besides the possibility to take advantage of government incentives on the production of electricity from renewable sources in Italy, that photovoltaic panels were installed on the roof of the winery in 2011.

The power of the plant installed is about 46.20 kW for a total surface of 350 m^2 and is made of polycrystalline silicon solar panels. The electricity produced by the photovoltaic system, 52,000 kWh per year, manages to cover 70% of all consumption of the winery while the rest is entered into the electricity grid and resold obtaining a significant additional income. The return on investment for this farm is around 12 years (total investment of 154,000 EUR).

By this way, the holding has decreased its total energy consumption by **16%** and its total GHG emissions by **9%**.

Conclusions

The creation of a common assessment tool, applicable in the four major European countries in terms of GHG emissions from the agricultural sector, helped identify the main sources of energy consumption and GHG emissions on over 125 farms. Three years of monitoring this network of farms showed that climate change mitigation on farms is indeed feasible, whatever the agricultural system.

Energy and climate assessments at the farm level open new perspectives, helping farmers to understand the operation of their farm. New lessons can be learnt and useful information can be obtained to embark farmers on the road towards the implementation of reduction actions

The assessment stage is essential to target the appropriate reduction measures and also to determine the potential for improvement of the climate footprint. The assessments results highlight a large variability in the levels of energy consumption and GHG emissions within the same farming system. Reduction potentials are closely related to these levels of performance, explaining why leeways differ between farms. The most sober farms often present modest reduction potentials (10%), while those who consume the most can sometimes have much more significant reduction potentials: about 30 to 40%!

Actions needed to reduce energy consumption and GHG emissions at the farm level do not always require investments: technical assistance to farmers by agricultural advisors specifically on agronomic and livestock-focused mitigation measures seems necessary to foster progress of the agricultural sector as a whole. Thus training and sensitisation of agricultural advisers to these assessment approaches appear to be essential.

Actions to be implemented to fight against climate change at the farm level have to be planned carefully and fit in a long-term timeframe. Short or medium term actions are generally applicable on farms, however the action plan approach should also include measures with a longer-term perspective to inform future decisions. The reflections on carbon sequestration in agricultural soils are also part of a longer-term approach.

In general, the fight against climate change can be an opportunity for the agricultural sector, helping farmers to be more competitive especially if they reduce their dependence on fossil energies. In the coming years, future subsidies could also be subject to the demonstration of a proper climate performance. Authorities at various levels (European, national and regional) will have to support farmers through incentive regulations, but also by supporting the financing of investments that help to obtain reductions. Finally, the growing interest of consumers related to the identification of the environmental and climate foot- print of food will certainly support initiatives to deploy climate friendly agricultural practices.

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# Acknowledgment

The partners of the *AgriClimateChange* project would like to thank warmly all the farmers who voluntarily joined the network of 120 farms in Germany, Italy, France and Spain. During these 3 years, their commitment was essential to the realization of the assessments in very diversified regions and farming systems. Their interest and understanding of the issue allowed constructive exchanges, which sometimes have been concretized by the implementation of improvement measures whose benefits have been monitored. These experiences generate knowledge that will be useful for all farmers who would like to engage in the reduction of their climatic and energy footprint.

Content:
Partners of the *AgriClimateChange* project

Graphic design, illustrations:
Eric Péro (spyro) - www.imageric.fr

Printed by
Imprimerie Trèfle in 500 copies

september 2013

Co-funders

Baden-Württemberg
MINISTERIUM FÜR LÄNDLICHEN RAUM UND VERBRAUCHERSCHUTZ

Sparkasse Singen-Radolfzell

Bioenergie Region Bodensee

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